# Tau Charm flavor factory

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**International Workshop on $e^+e^-$ collisions from phi to psi (PHIPSI13)**

**Rome, September 9-12, 2013**

# Tau Charm flavor factory

- features and physics prospects
- more info in Workshop on Tau Charm at High Luminosity, La Biodola, 26-31 May 2013
  `https://agenda.infn.it/conferenceDisplay.py?confId=6193`
- (this is a rough presentation, asked just few days before the conference)

# Accelerator scheme superB inspired

- Energy tunable currently in the range $\mathbf{E_{cm} = 2\text{-}4.8\ GeV}$
- $\mathbf{2 \times 10^{35}\ cm^{-2}\ s^{-1}}$ **maximum** peak luminosity at the $\tau$/charm threshold and upper
- Low currents and crab waist solution for the interaction region
  - Low power consumption
- Polarization available on one beam (65-70%)
- A symmetric machine
- Compact dimensions (about 340 Meters for the rings)
- Only positrons damping ring
- Competitive luminosity also at lower energy (currently 2 GeV)

# Accelerator study group

## LNF team

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- A. Drago
- S. Guiducci
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- S. Tomassini

## ESRF & Pisa team

- P. Raimondi
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- E. Paoloni

## LNS team

- G. Schillaci
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## CabibboLab team

- S. Bini
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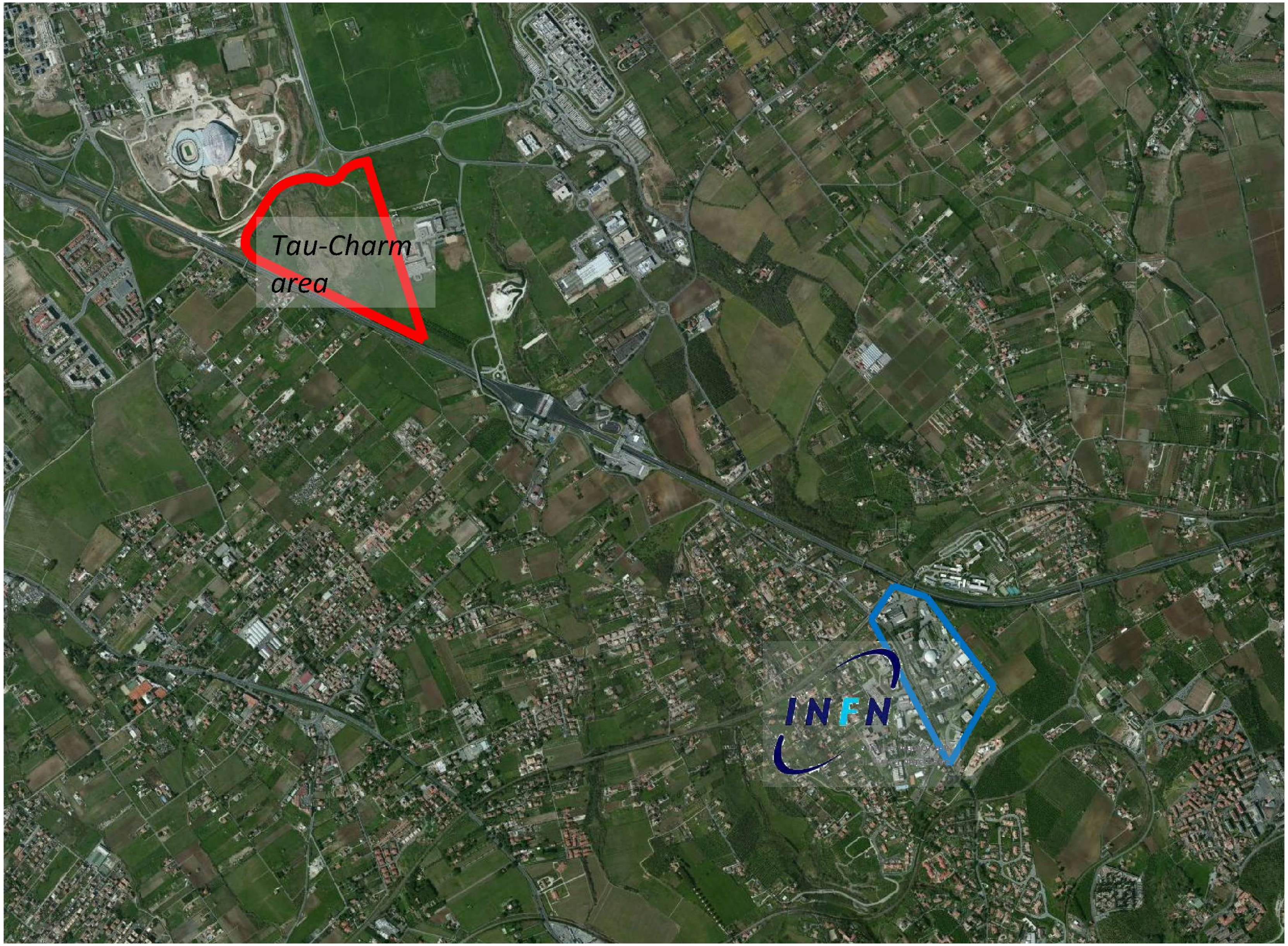
- M. D'Agostino
- M. Del Franco
- A. Delle Piane
- E. Di Pasquale
- G. Frascadore
- S. Gazzana
- R. Gargana
- S. Incremona
- A. Michelotti
- L. Sabbatini

# Tau charm middle 2013

- ✓ lattice design DONE
- • beam-beam and crabbed waist (assumed similar to SuperB)
- ✓ dynamic aperture DONE
- • electron cloud IN PROGRESS
- ✓ Touschek effect and beam-gas scattering DONE
- • Interaction region IN PROGRESS
- • QD0 IN PROGRESS
- ✓ Low emittance tuning, tolerances DONE
- • RF & Impedance
- ✓ Feedback DONE
- ✓ Injection DONE
- ✓ Site considerations DONE
- ✓ Polarization DONE
- • Machine availability ?

# Accelerator site



## Physics case

- tau LFV (particularly $\tau \to \mu\gamma$) and CPV
- CPV in $D^0$ mixing and decay
- EW physics ($\sin\theta_W$ at the $J/\psi$ peak using polarized beams)
- search for dark forces
- radiative return measurements
- spectroscopy

# CPV IN D MIXING

- D mixing is described by:
  - $M_{12}$
    - SM: long-distance dominated, not calculable (today, see lattice progress on $\Delta M_K$) but real
    - NP: short distance, calculable w. lattice
  - $\Gamma_{12}$
    - SM: not calculable but real
  - $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$
    - $\mathrm{Im}\, M_{12} = -|M_{12}| \sin\Phi_{12}$ pure NP effect

# CPV IN D MIXING II

- Define $|D_{S,L}| = p|D^0| \pm q|D^0|$ and $\delta = (1-|q/p|^2)/(1+|q/p|^2)$. All observables can be written in terms of $x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$ and $\delta$, with

$$\sqrt{2}\,\Delta m = \mathrm{sign}(\cos\Phi_{12})\sqrt{4|M_{12}|^2 - |\Gamma_{12}|^2 + \sqrt{(4|M_{12}|^2 + |\Gamma_{12}|^2)^2 - 16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,,$$

$$\sqrt{2}\,\Delta\Gamma = 2\sqrt{|\Gamma_{12}|^2 - 4|M_{12}|^2 + \sqrt{(4|M_{12}|^2 + |\Gamma_{12}|^2)^2 - 16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,,$$

$$\delta = \frac{2|M_{12}||\Gamma_{12}|\sin\Phi_{12}}{(\Delta m)^2 + |\Gamma_{12}|^2}\,, \qquad (7)$$

- Notice that $\phi = \arg(q/p) = \arg(y + i\delta x) - \arg\Gamma_{12}$
- $|q/p| \neq 1 \Leftrightarrow \phi \neq 0$ clear signals of NP

Ciuchini et al; Kagan & Sokoloff

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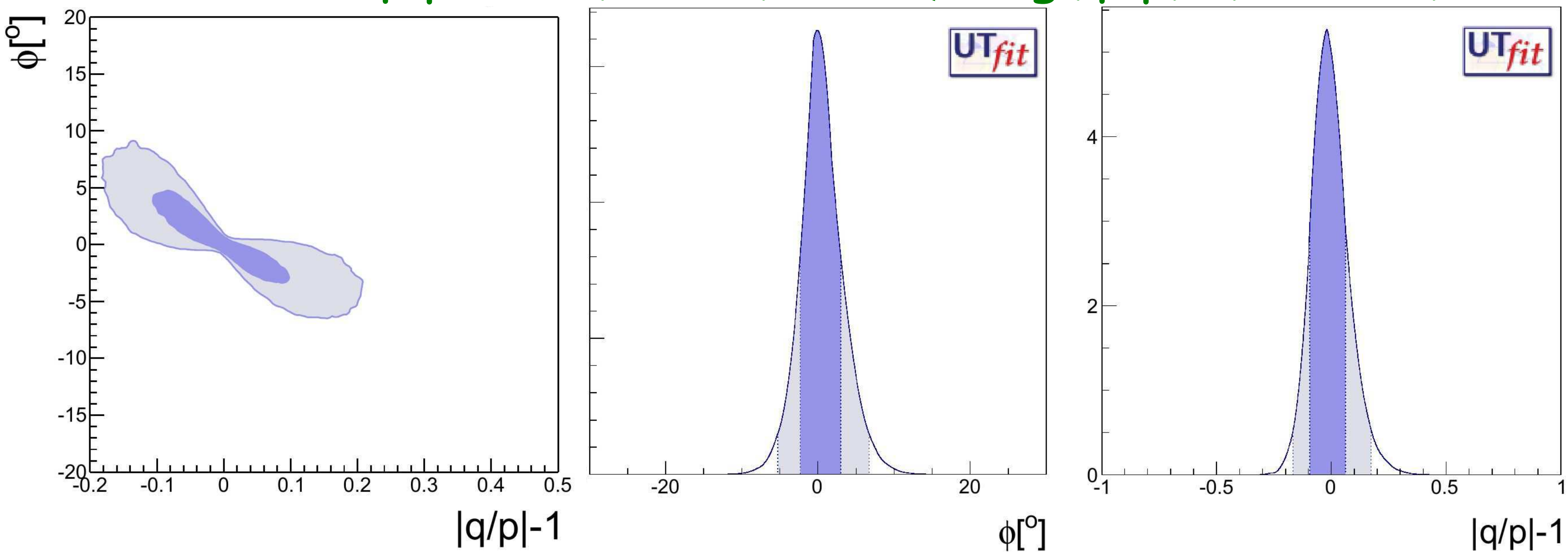
# CPV IN MIXING TODAY

- updating the UTfit average with latest LHCb data we obtain:

$x = (4.2 \pm 1.8)\ 10^{-3}$, $y = (6.4 \pm 0.8)\ 10^{-3}$,

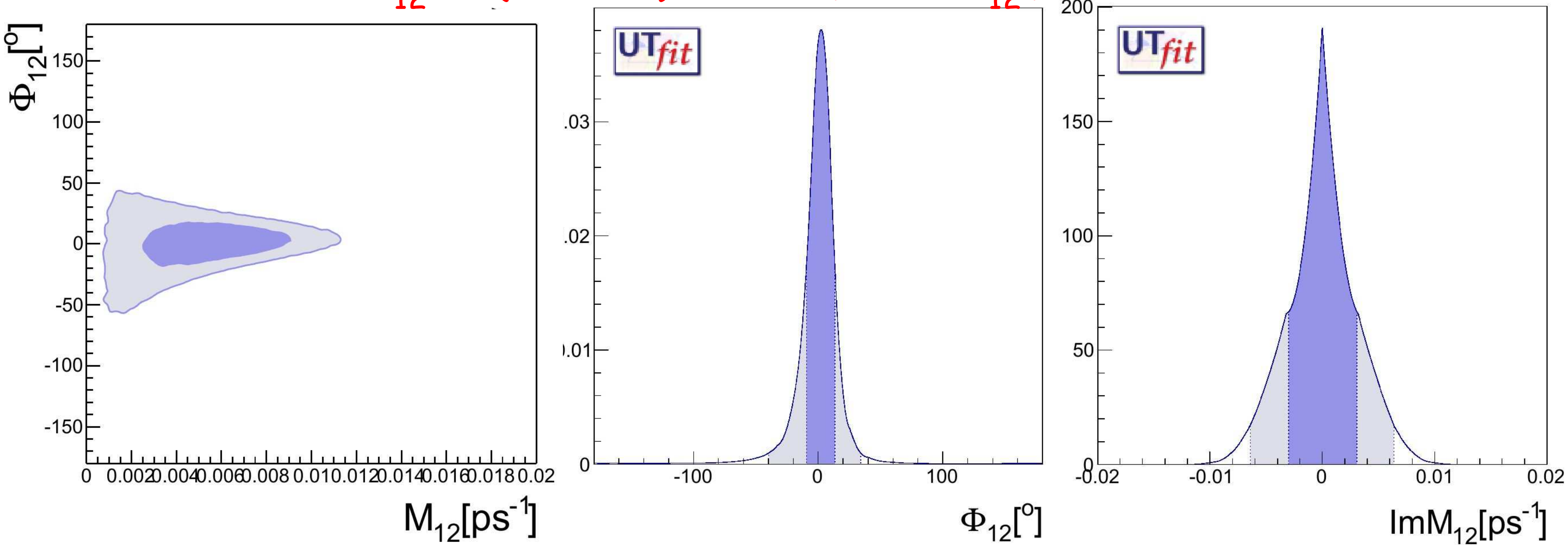
$|q/p|-1 = (-2 \pm 8)\ 10^{-2}$, $\phi=\arg(q/p)=(0.3\pm2.6)^\circ$



# CPV IN MIXING TODAY II

- The corresponding results on fundamental parameters are

$|M_{12}| = (5 \pm 2)/\text{fs}$, $|\Gamma_{12}| = (16 \pm 2)/\text{fs}$,
$\Phi_{12} = (2 \pm 11)^\circ$ and $|\text{Im}\, M_{12}| < 6/\text{fs}$ @ 95%



# IMPLICATIONS FOR NP SCALE

- The upper bound on $|\mathrm{Im}\, M_{12}|$ can be turned into a bound on the coefficients of the relevant effective Hamiltonian:
  - $H_{eff}=\Sigma_i (c_i/\Lambda^2)\, O_i^6$
- A lower bound of the NP scale $\Lambda$ can be obtained for fixed couplings $c_i$, or an upper bound on the couplings $c_i$ can be obtained for fixed NP scale $\Lambda$

# D MIXING @ SYMMETRIC e+e-

- Time-integrated decays of quantum-correlated D-anti D pairs, with Dbar decaying in a flavour-specific final state:

  $1 - r_f \cos(\delta_f+\phi)\,(1+\eta_c)\,y + r_f \sin(\delta_f+\phi)\,(1+\eta_c)\,x + O(x^2, y^2)$, with $r_f=\bar{A}_f/A_f$, $\delta_f$ strong phase

- At the $\psi(4040)$ produce $DD^*$ pairs, obtain $\eta_c=-1$ for $D^*\to D\pi$ and $\eta_c=1$ for $D^*\to D\gamma$, exploit the linear terms for $\eta_c=1$ to measure $x$, $y$, $\phi$

Bondar, Poluektov & Vorobiev

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# D MIXING CPV REACH

| | Belle-II (50 $ab^{-1}$) | LHCb upgr. (50 $fb^{-1}$) | Tau-charm (9 $ab^{-1}$) |
|---|---|---|---|
| x ($10^{-4}$) | 8 | 1.5 | 1.7 |
| y ($10^{-4}$) | 4 | 1 | 1.7 |
| $\|q/p\|$-1 ($10^{-2}$) | 5 | 1 | 0.5 |
| $\phi$ (°) | 2.6 | -- | 0.5 |

- Belle-II does not include strong phases from BES-III or Tau-charm
- LHCb upgrade x, y & $\phi$ should be revised as measurement from $K_s\pi\pi$ should allow for CPV
- Tau-charm extrapolated from Bondar et al
- Only Tau-charm allows for sub-degree determination of $\arg(M_{12})$ and $\arg(\Gamma_{12})$

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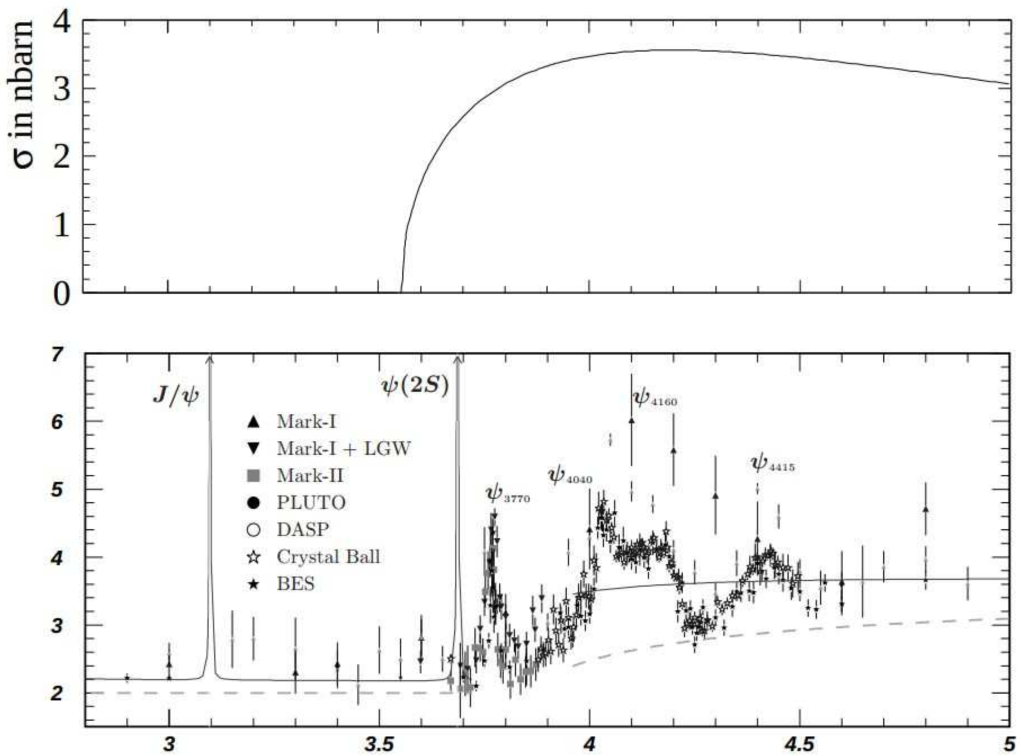
# Tau → mu gamma

# Tau pairs production rates

at √s = 4.04 GeV $\sigma_{ee\to\tau\tau} \cong 3.4$ nb
at √s = 10.58 GeV $\sigma_{ee\to\tau\tau} \cong 1.0$ nb

Tau-Charm (L=2 x $10^{35}$ cm$^{-2}$s$^{-1}$) ≅ **7 x $10^9$** $\tau\tau$ events per year
BELLE II (L=8 x $10^{35}$ cm$^{-2}$s$^{-1}$) ≅ **8 x $10^9$** $\tau\tau$ events per year
[Snowmass year = $10^7$ s]



# $\tau \to \mu \gamma$

Eγ for ISR ττγ background is lower than Eγ for $\tau \to \mu\gamma$
when the machine is operated at $\sqrt{s}$ = 4.2 GeV

Eγ (CMS) from $\tau \to \mu\gamma$ and ISR(ττγ)

Y(4s)

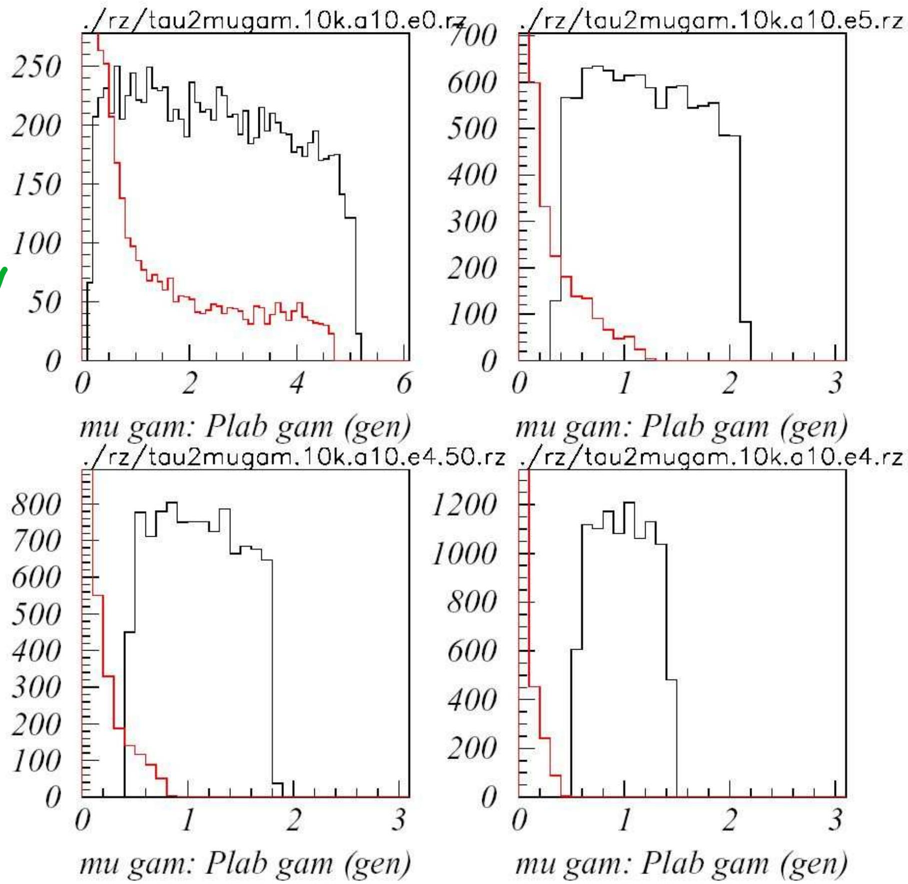
$\sqrt{s} = 10.58\,GeV$

$\sqrt{s} = 5.0\,GeV$

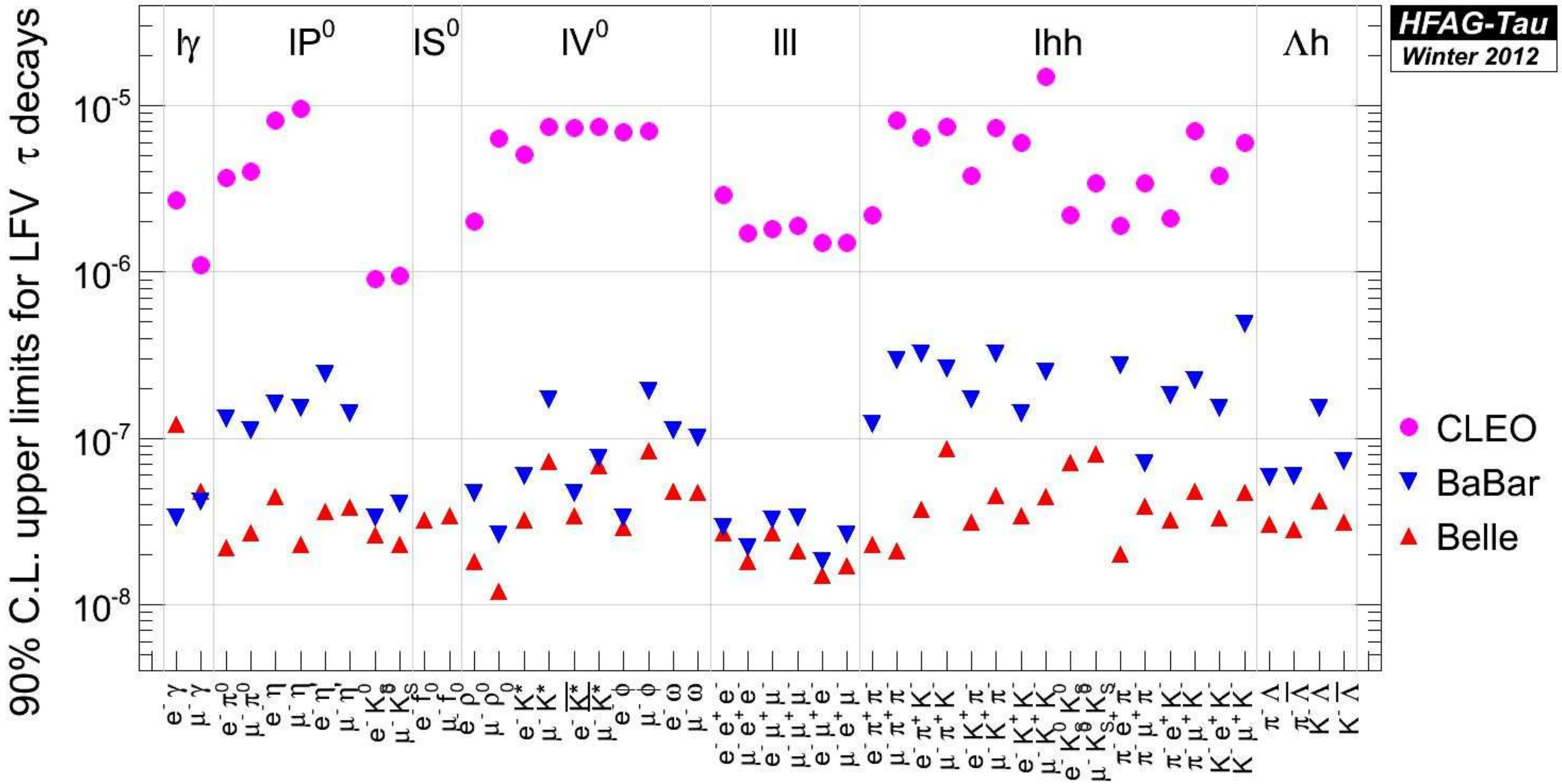
maximum σ=3.6nb

$\sqrt{s} = 4.25\,GeV$

$\sqrt{s} = 4.0\,GeV$



# Tau LFV discovery potential




- BELLE-II [50ab$^{-1}$]: B($\tau \to \mu\gamma$) < 5 x $10^{-9}$, systematically limited
- tau-charm: B($\tau \to \mu\gamma$) < 5 x $10^{-10}$, statistically limited

V.Druzhinin, La Biodola, May 2013

(need factor 30 suppression of pion to muon misidentification, achievable with TOF or FARICH)

# Also CP violation in $\tau$ decays

- Number of tau events at tau-charm and belle-II is comparable
- Final states in CP-violating observables involve multi-h (K or pi) + neutrino. More studies are needed to make a sensible comparison between the efficiency of tau-charm and Belle-II on these modes
- Polarization increases the number/improves the sensitivity of CP-violating observables and provides a better control on systematics

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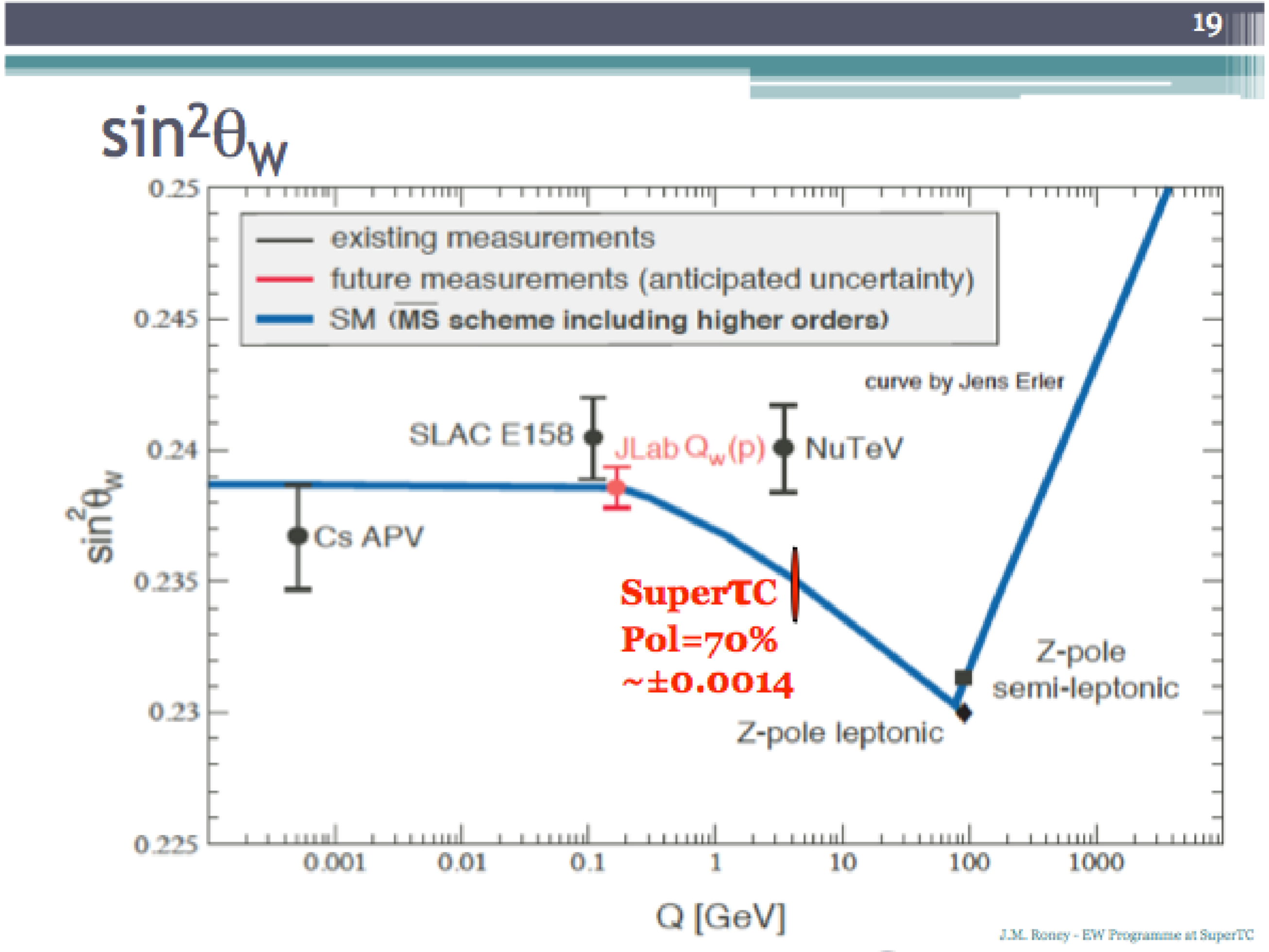
# Precision EW tests



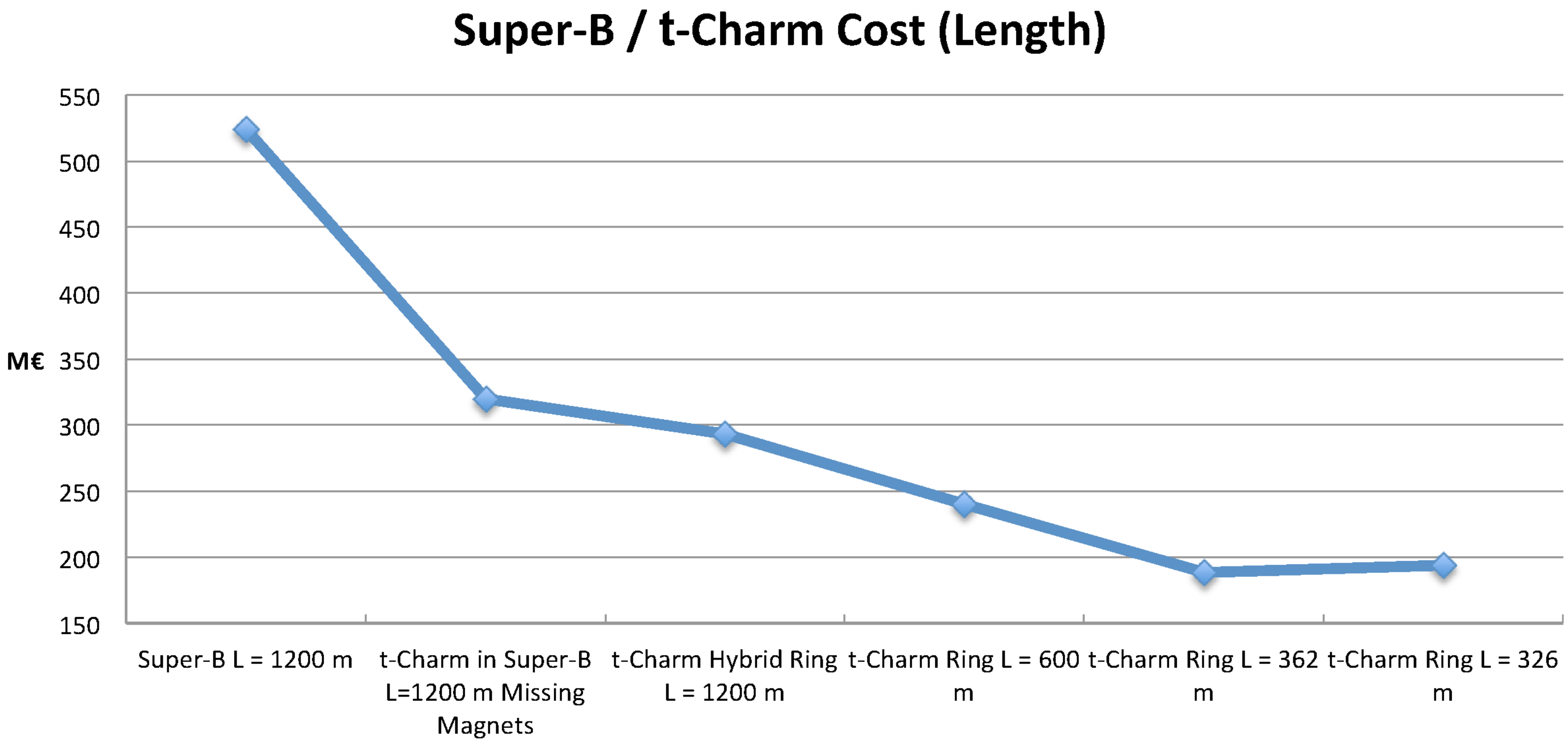
## Detector

- no fundamental technology advances are necessary
- general purpose, hermetic, fast detector needed, symmetric beams
- large amount of expensive components can be re-used from *BABAR*
- new drift chamber (possibly with cluster-counting)
- a silicon vertex detector is not mandatory
- TOF
- fast front-end electronics
- studies on-going since May 2013

# Tau charm Factory case
## (work in progress)

- Linac for **2.9** GeV $e^-$ and **2.3** GeV $e^+$;
- Linac Length around **200** m;
- Two **Symmetric** rings;
- Storage Ring Length -> **600** -> **362** -> **326** m.

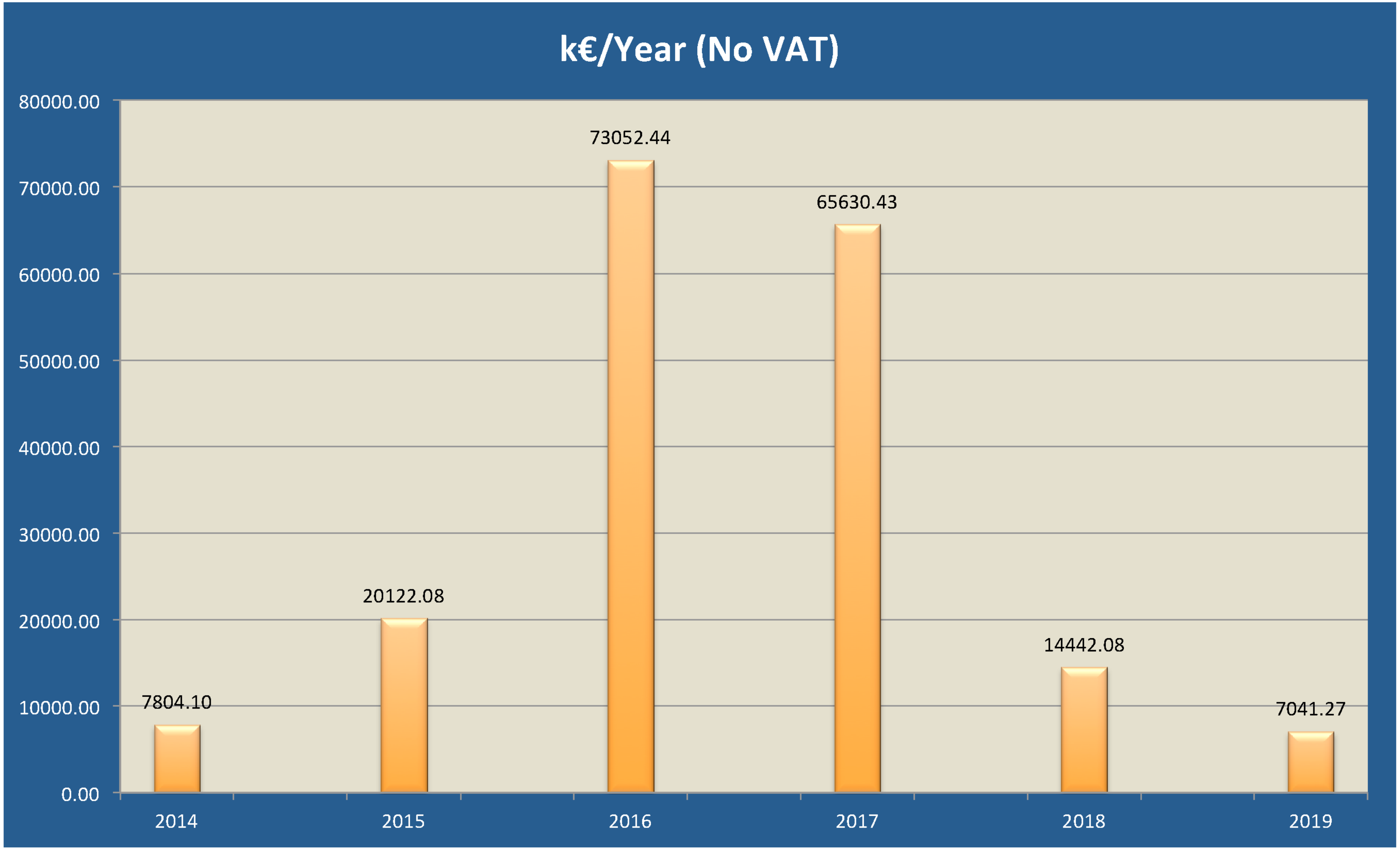
# Super-B -> Tau-Charm Cost



# Operating cost

- Around 15Meuros/year

# Tau charm spending profile (bare cost) (very preliminary )



# Conclusions

- luminosity goal supported by consolidated studies profiting from work done for SuperB
- sound cost and planning estimates exist, working on contingency estimates
- accelerator costs match funding approved for SuperB
- discovery machine and powerful EW - QCD laboratory
- on specific channels can challenge and overcome existing and planned facilities in the next decade