Cost-benefit analysis of the LHC with and without the High Luminosity project

(preliminary results)

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with

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SOCIO-ECONOMIC IMPACT OF LHC TO 2025 AND BEYOND

SKILLS

- Project Leadership
- Developing and Maintaining Collaborations
- Critical Analysis
- Communication Skills
- Problem-solving Capacity
- Technical Skills
- Scientific Skills

Human capital (H)

Students 53% (19400)

Post-docs 47% (17400)

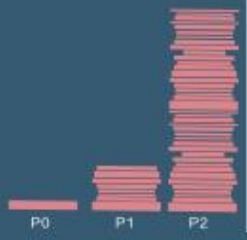
Students & Post-docs (1993-2025)

LHC preprints & publications (1993-2025)

808'000
P2: Publications by external scientists citing P1.

228'000
P1: Publications by external scientists citing P0.

23'000
P0: LHC related publications by CERN staff and collaborators.

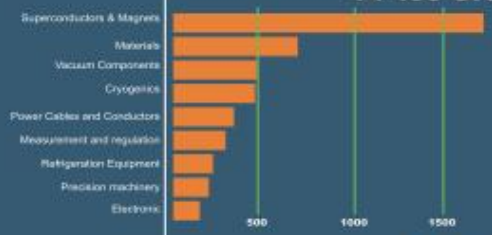


Tech spillovers (T)

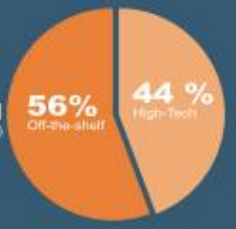
Technological spillovers

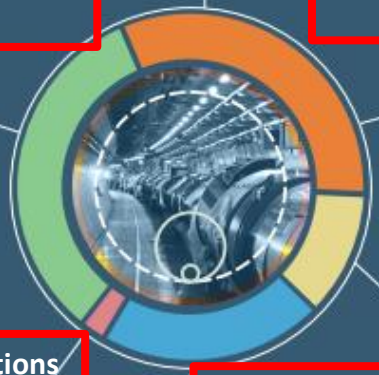
- 1'400 Firms
- >30 Countries
- 14'400 Orders

14'400 Orders



INNOVATION (1995-2008)





Cultural Effects (C)

3'000'000 Visitors to CERN

1'000'000 Visitors to travelling exhibitions

17'000'0 social media users

446'000'000

Publications (S)

Existence value (*EXV*)

How much taxpayers contribute?

415 Million taxpayers
21 Member Countries
2 € pro per Person

LHC IMPACT (1993-2025)

- Scientists (preprints & publications): **2%**
- Firms (technological spilovers): **32%**
- Students and post-docs (human capital): **33%**
- General public (cultural effects): **12%**
- Taxpayers (science as public good): **21%**

References:

Andrea Bastianin and Massimo Florio (University of Milan) for the University of Milan-CERN joint project on the cost-benefit analysis of HL-LHC and the Future Circular Collider. Based on:

- Florio, M., Forte, S., & Sirtori, E. (2016). "*Forecasting the socio-economic impact of the Large Hadron Collider: A cost-benefit analysis to 2025 and beyond.*" Technological Forecasting and Social Change, 112, 38-53.
- Camporesi, T., Catalano, G., Florio, M. & Giffoni, F. (2017) "*Experiential learning in high energy physics: a survey of students at the LHC.*" European Journal of Physics, 38(2), 025703.

fcc.web.cern.ch

Outline

- Social CBA of research infrastructures
- Application to HL-LHC: methods and scenarios
- Benefits & costs
- Results
- Next Steps

Introduction to social CBA of research infrastructures

EN

Horizon 2020

Work Programme 2018-2020

4. European research infrastructures (including e-Infrastructures)

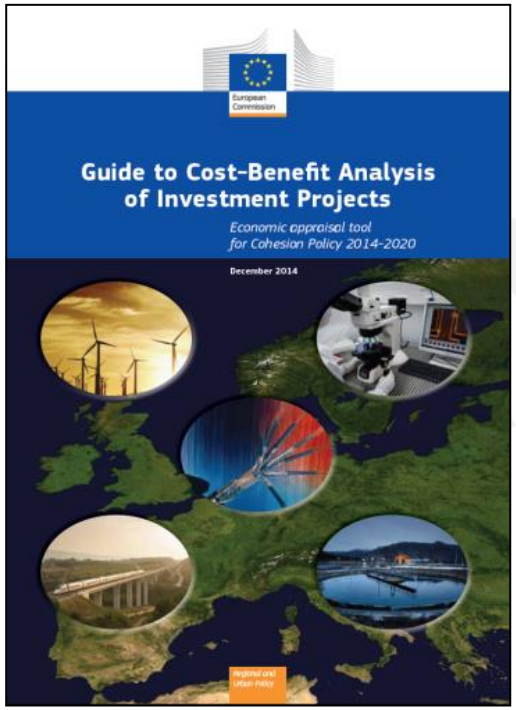
Important notice on the Horizon 2020 Work Programme

This Work Programme covers 2018, 2019 and 2020. The parts that relate to 2019 and 2020 are provided at this stage on an indicative basis. Such Work Programme parts will be decided during 2018 and/or 2019.

(European Commission Decision C(2017)7124 of 27 October 2017)

"(…) The ESFRI roadmap, updated periodically, identifies the needs of the European scientific community in terms of research infrastructures (…) Societal and economic benefits of the infrastructure should be analysed to carry out a Cost-benefit analysis"

[H2020 Work Programme 2018/20]



CBA Guide: European Commission (2014). "*Guide to Cost-Benefit Analysis of Investment projects*". DG Regional and Urban Policy.

- **CBA needed** for funding major projects under the EU Structural Funds;
- **Reference guide** for evaluation of RI under H2020 program [EC Decision C(2017)7124]

Social CBA of RI - Further readings

- **Special Issue**: Del Bo, Florio and Forte (2016). "*The social impact of research infrastructures at the frontier of science and technology: The case of particle accelerators*"

- **CBA of RI - Theory**: Florio, Sirtori (2016). "*Social benefits and costs of large scale research infrastructures*" [**FS, 2016**]
- **CBA of LHC**: Florio, Forte, Sirtori (2016). "*Forecasting the socio-economic impact of the Large Hadron Collider: A cost–benefit analysis to 2025 and beyond*" [**FFS, 2016**]

- Camporesi et al (2017) "Experiential learning in high energy physics: a survey of students at the LHC" *Eur. J. Phys.*

- Florio, Castelnovo, Forte, Rossi, Sirtori (2016) "The Economic Impact of CERN Procurement: Evidence from the Large Hadron Collider." https://arxiv.org

- Florio, Forte, Pancotti, Sirtori, Vignetti (2016) "Exploring cost-benefit analysis of research, development and innovation infrastructures: an evaluation framework", https://arxiv.org

- Catalano , Florio, and Giffoni (2016), Willingness to pay for basic research: a contingent valuation experiment on the large hadron collider, https://arxiv.org

- Florio, Giffoni, Giunta, Sirtori (2017) *"*Big Science, Learning and Innovation: Evidence from CERN Procurement*"*, Working Paper, Roma Tre University.

Social CBA of RI

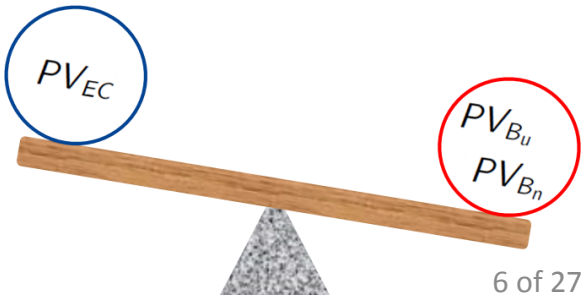
Methodology in a nutshell

$$\mathbb{E}\left(NPV_{RI}\right) = \mathbb{E}\left[\underbrace{\left(PV_{B_u} - PV_{EC}\right)}_{NPV_u} + PV_{B_n}\right]$$

- NPV_{RI}: Net Present Value (NPV) of a RI
- $NPV_u = PV_{B_u} - PV_{EC}$: benefits for users of the R
- $PV_{B_n} \approx EVX$: benefits for non–users $\approx$ "public good value" of scientific discovery
- PV_{EC}: economic costs (i.e. operating, inv. costs and externalities, if any)
- PV_{B_u}: benefits of stakeholders

$\Longrightarrow$ RI passes CBA if:

$$\mathbb{E}\left(NPV_{RI}\right) > 0$$



CBA of HL-LHC

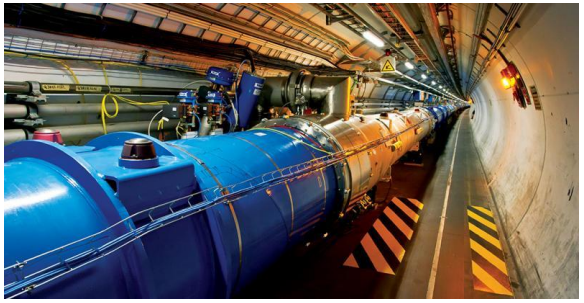
Baseline and counterfactual scenarios

- Baseline and counterfactual scenarios of the CBA are **CERN with and without the HL upgrade** of the LHC.

Baseline: HL-LHC

HiLumi
HL-LHC PROJECT

Counterfactual (CFS): operating LHC under normal consolidation



CBA of HL-LHC: the baseline

- Baseline: HL-LHC

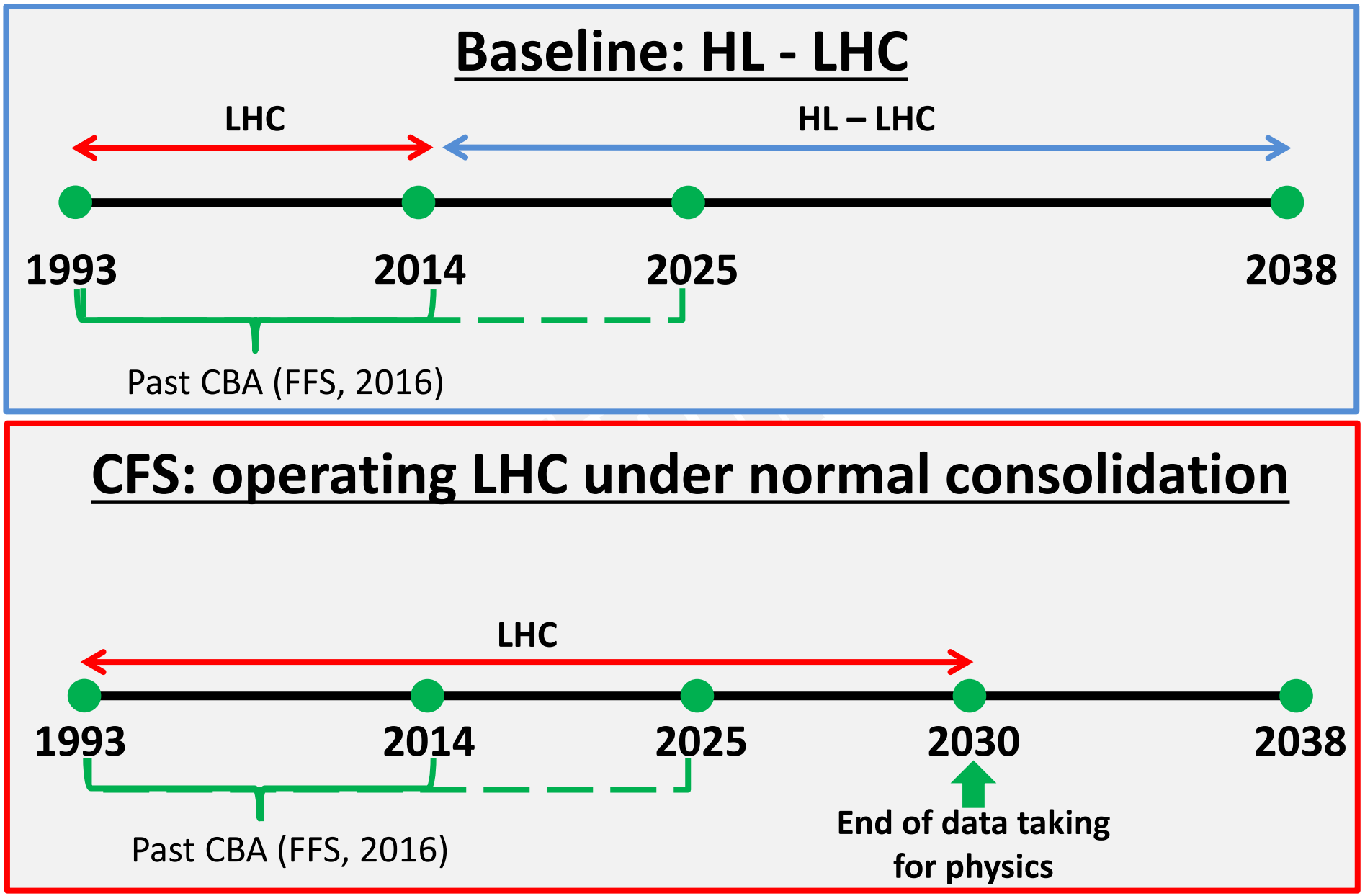
Notes: retrieved in Oct. 2017 from: https://project-hl-lhc-industry.web.cern.ch/content/project-schedule

CBA of HL-LHC: counterfactual scenario

- Counterfactual scenario: operating LHC under normal consolidation.
- 2025-30: gradual decrease of activity
- From 2031:
  - No more data taking for physics.
  - CERN personnel engaged in other programs.
  - LHC operated with “normal” investments (e.g. replacements, maintenance).
  - Equipment remains in the tunnel under appropriate monitoring and safety arrangements, but is not operated.
  - A minimum of cooling, ventilation, electricity, water supply and security would remain.

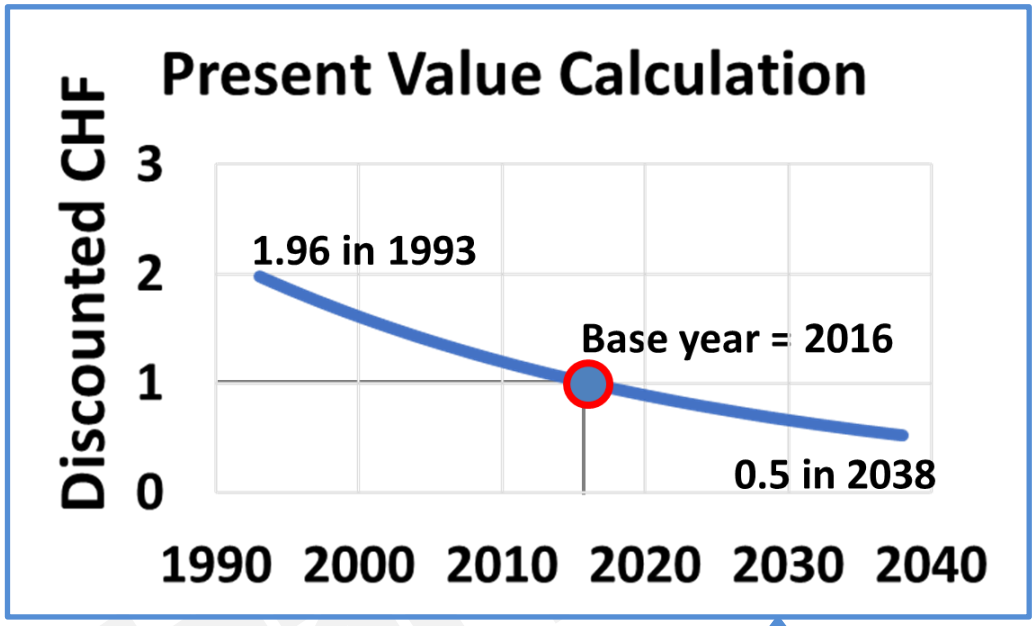
what if?

CBA of HL-LHC
Methodology & assumptions



CBA of HL-LHC

Methodology & assumptions



- **HL-LHC preferred to the CFS if:**

$$NPV_{HL\text{-}LHC} > NPV_{CFS}$$

- **Difference due to HL-LHC**:

$$\Delta NPV = NPV_{HL\text{-}LHC} - NPV_{CFS}$$

- Base year: 2016 (i.e. discounting and inflation adjustments)
- Discount rate: 3% (EC - CBA Guide).
- Present value:

$$PV = \sum_t \frac{1}{(1+0.03)^t}$$

with t = -23 (1993), …, 0 (2016), 22 (2038)

CBA of HL-LHC

Methodology & assumptions

- Horizon: 1993-2038 for cost and most benefits (but up to 2080 for certain benefits).
- Other issues:
  - 1993-14: baseline scenario (HL-LHC) corresponds to LHC (CBA by FFS).
  - 1993-25: operating LHC "under normal consolidation" corresponds to FFS's CBA of LHC.
  - In both scenarios undiscounted figures for 1993-14 are the same as those in FFS.
  - Scientific personnel cost: removed to avoid double-counting benefits.
  - Inflation adjustment: using CPI for CH only over the 1993-16 period.
  - Inflation and exchange rates after 2016: no attempt to model or forecast them.
  - Warning: FFS used 2013 as base year, discounted values are numerically different

CBA of particle accelerators: benefits

$$Benefits = \underbrace{(S + H + T + C)}_{PV_{Bu}} + \underbrace{EXV}_{PV_{Bn}}$$

arXiv.org

Scientists (S): 1993-2063

- Preprints & publications

Students & post-docs (H): 1993-2063

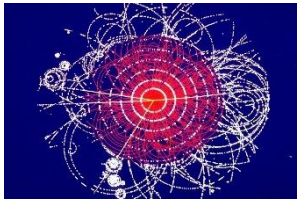
- Human capital formation

Firms (T) : 1993-2038

- Technological spillovers and open access software

General public (C): 1993-2038

- Cultural effects of outreach

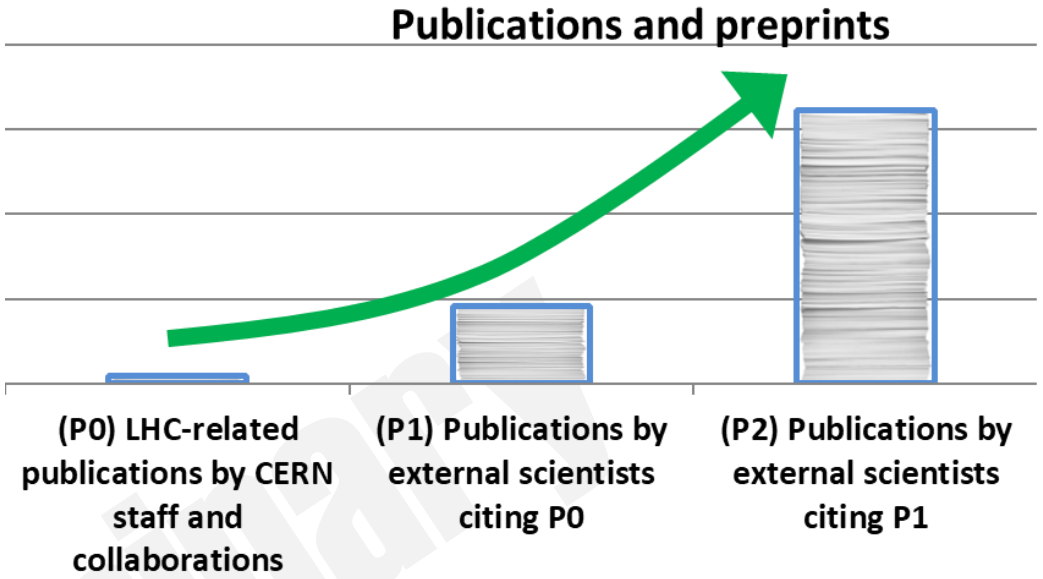


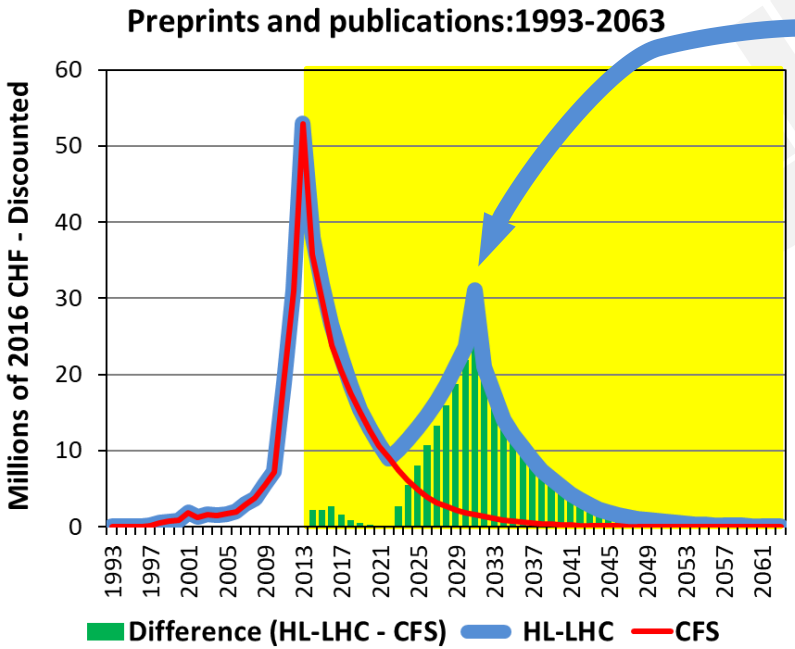
Taxpayers (EXV): 1993-2038

- Existence value: science as a public good

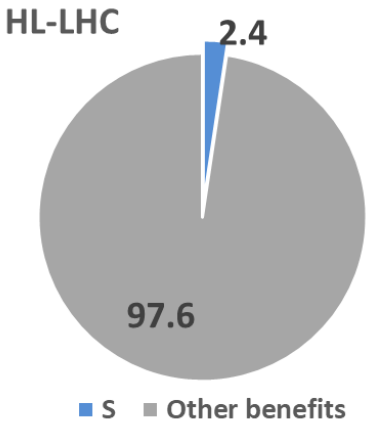
Scientists (S) - Preprints & publications (PP: 1993-2063)

- (P0) HL-LHC (or LHC) PP by CERN staff and collaborations (Value = cost prod.)
- (**P1**) PP by external scientists citing P0
- (P2) PP by external scientists citing P1 (value = 0)

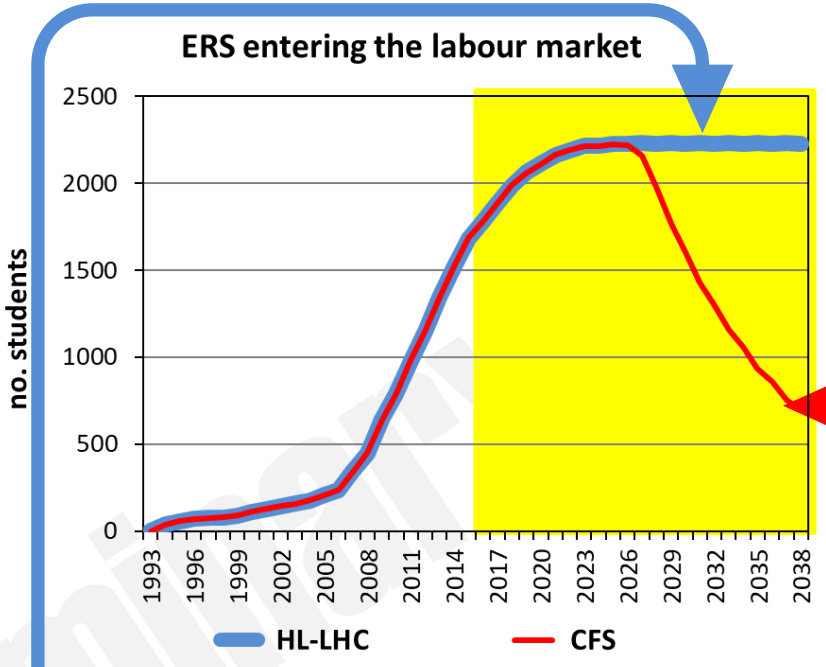


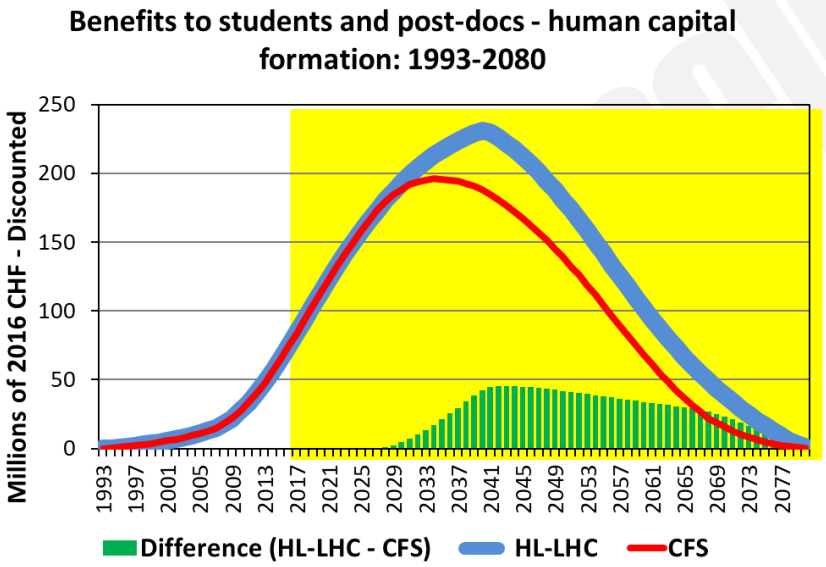


- **P1** benefits extend to 2036.
- HL-LHC: new peak in 2031
- i.e. new experiments and new physics?

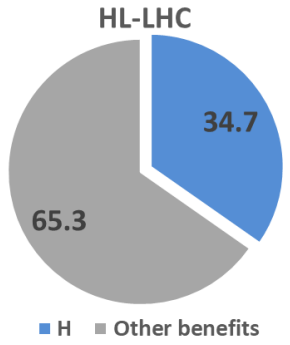


Early stage researchers (H) - Human capital effects (1993-2080)

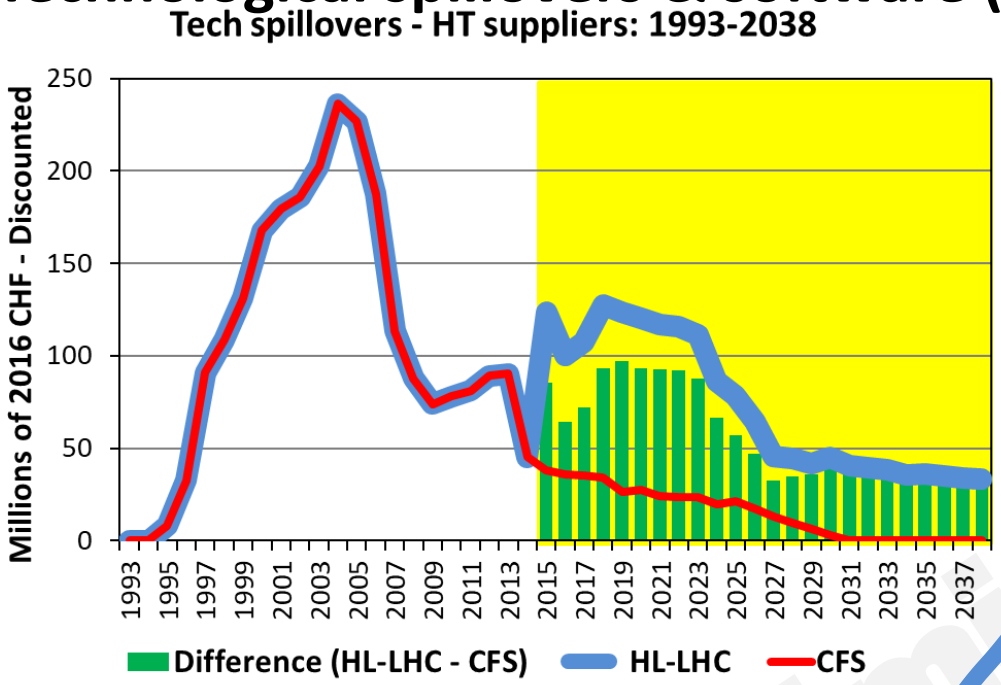


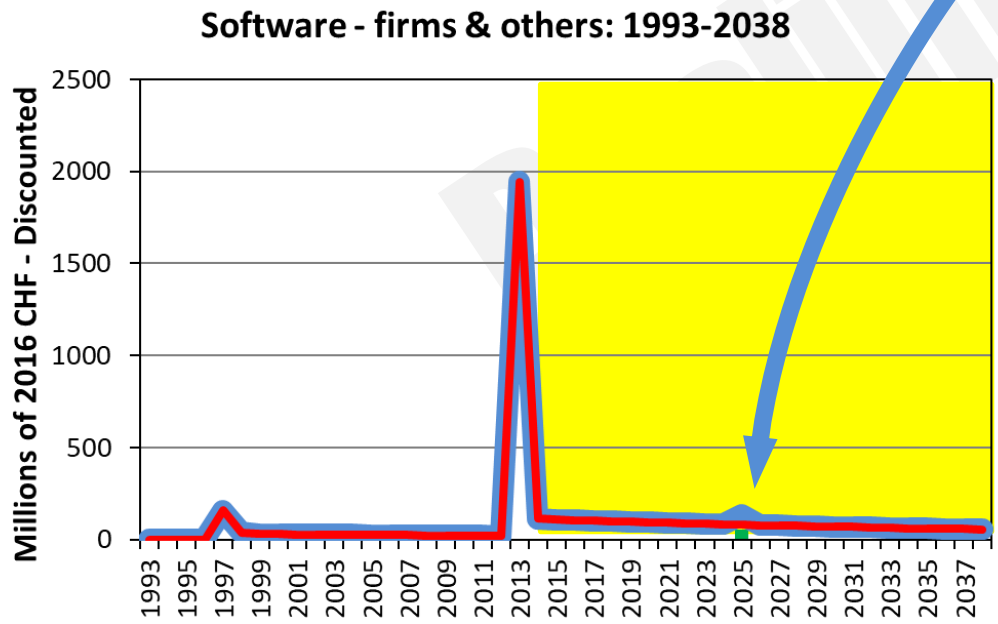


- HL-LHC: by 2025 no. ERS = full capacity
- CFS: without a major technological improvement, CERN loses attractivity for ESR



Technological spillovers & software (T) – Firms (1993-2038)



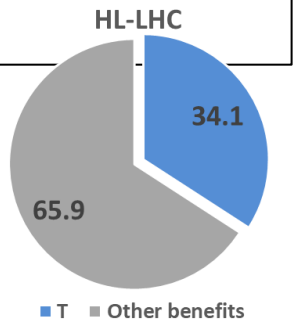


- Tech spillovers proportional to costs
- Share of HT procurement for HL-LHC greater than for CFS

- HL-LHC requires a substantial revision of current software to manage an increased experimental data flow
- HL-LHC: new peak in 2025 similar to Root in 1997 in FFS.
- Very conservative assumption: new codes?

"The High-Luminosity LHC (…) is planned to come online in around 2026. By this time, the total computing capacity required by the experiments is expected to be 50-100 times greater than today, with data storage needs expected to be in the order of exabytes"

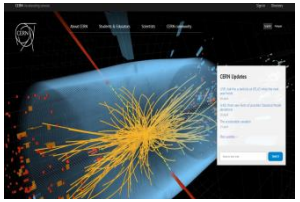
Source: https://home.cern/about/updates



Cultural Effects (C) – General public (1993-2038)

Visitors to CERN, experiments & travelling exhibitions

Social media users

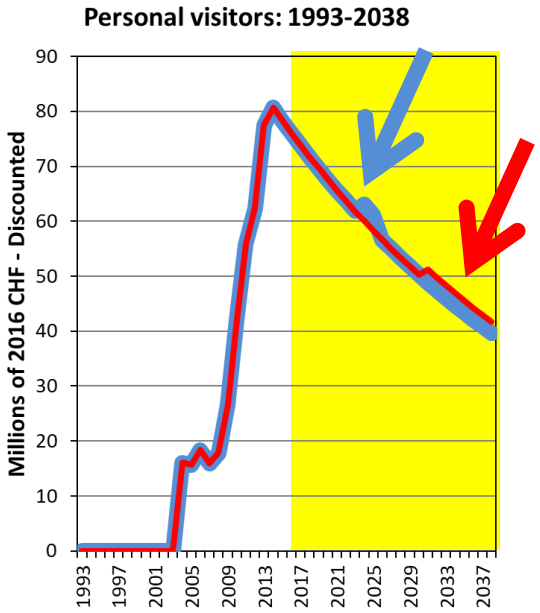


Website visitors & mass media on general public

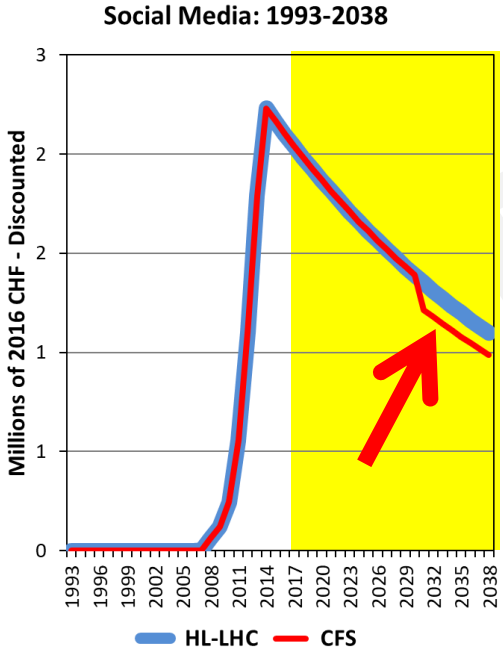
LHC@home
Volunteer computing for the LHC

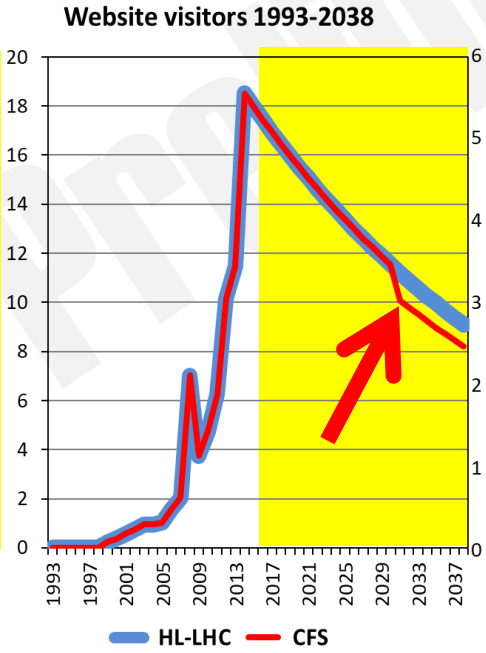
Volunteer computing

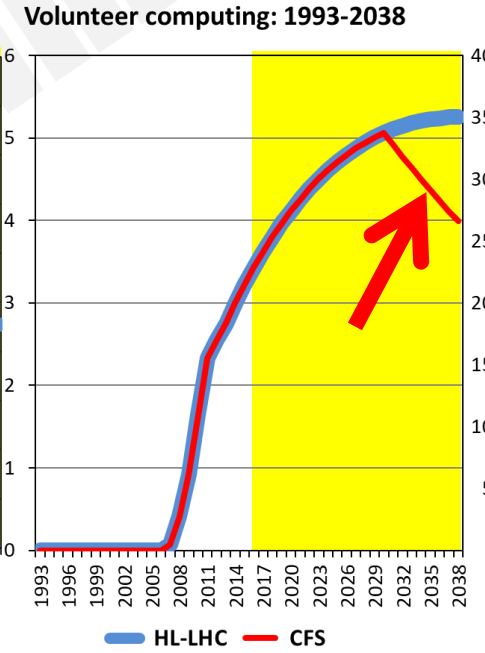
Cultural Effects (C) – General public (1993-2038)



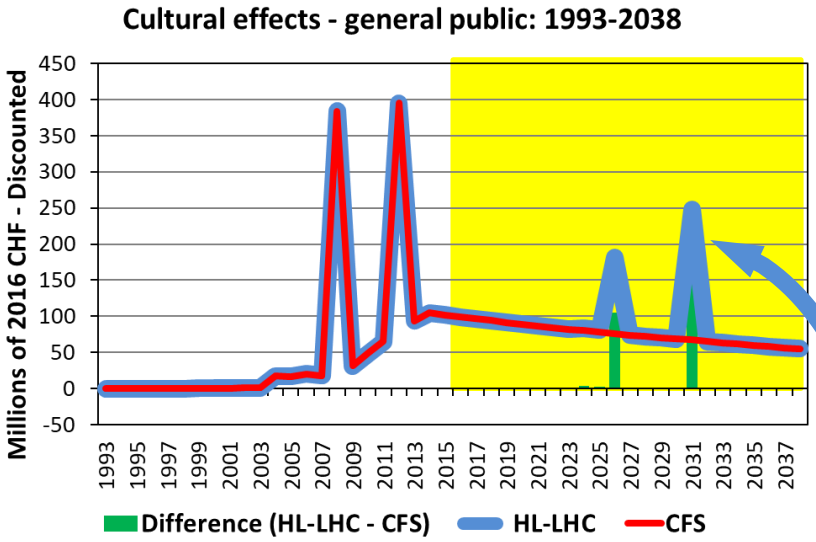
- Personal visitors: increase during long shut down 4 for HL-LHC and increase after 2030 for CFS
- Website visitors and social media users: benefits decreases by 5% after 2030 for CFS.
- Volunteer computing: benefit decreases after 2030 for CFS
- Mass media on the general public: two spikes in 2026 (start of Run 4) and in 2031 (if new discovery).

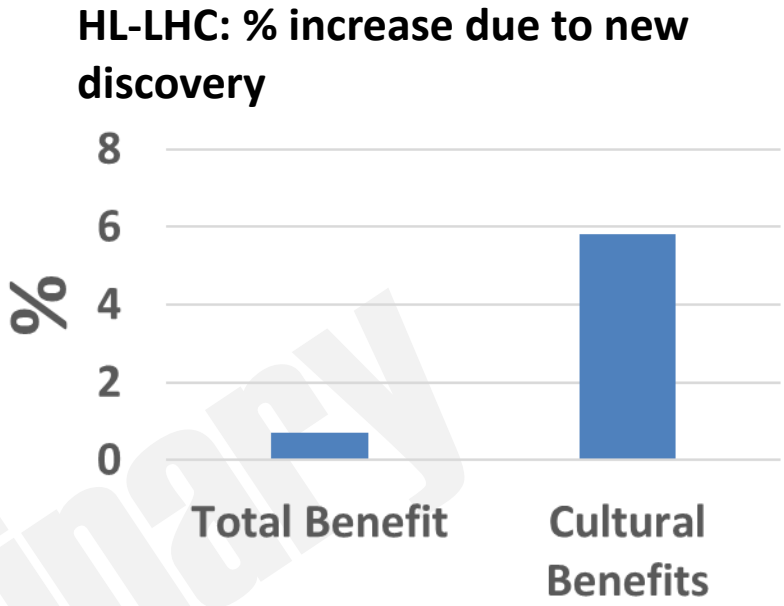


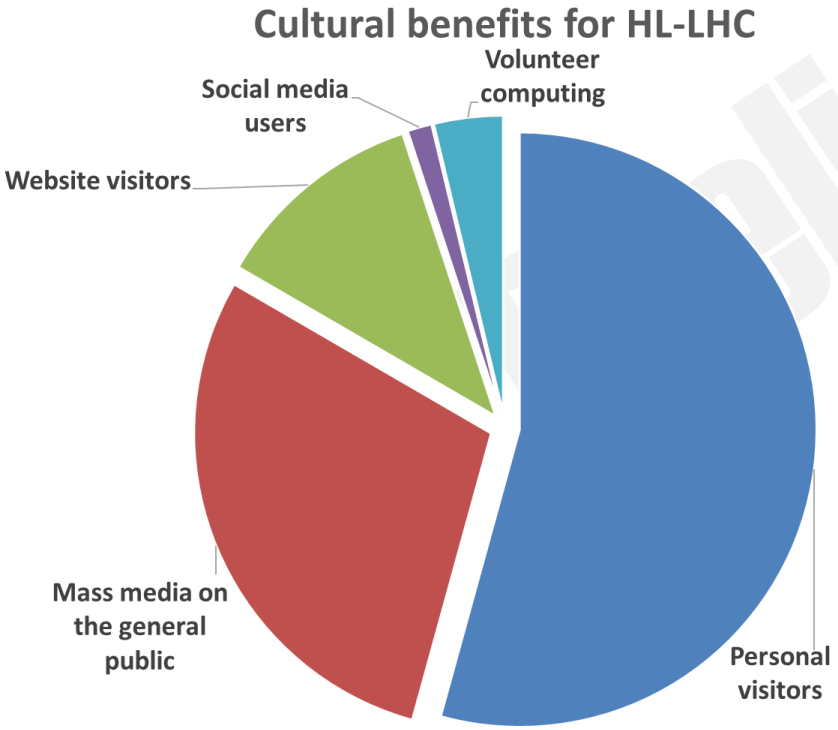




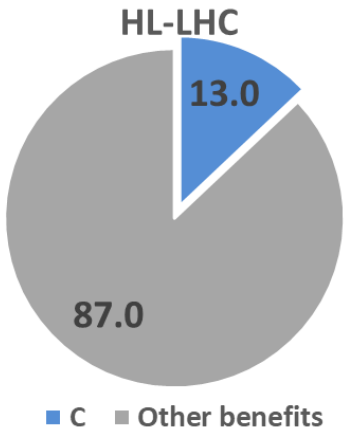
Cultural Effects (C) – General public (1993-2038)







- Impact of new discovery
- A scenario without new discovery:
  - less than 5% decrease in total benefits



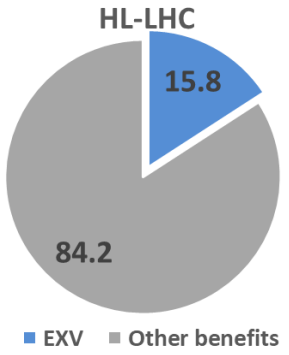
Existence value (EVX) – Scientific knowledge as public good

"A resource or a service might be valued even if it is not consumed. Such values are referred to as non-use values (…) this should be reflected in the cost-benefit analysis (…) among these are existence values" (Johansson and Kriström, 2015, pp. 24–25).

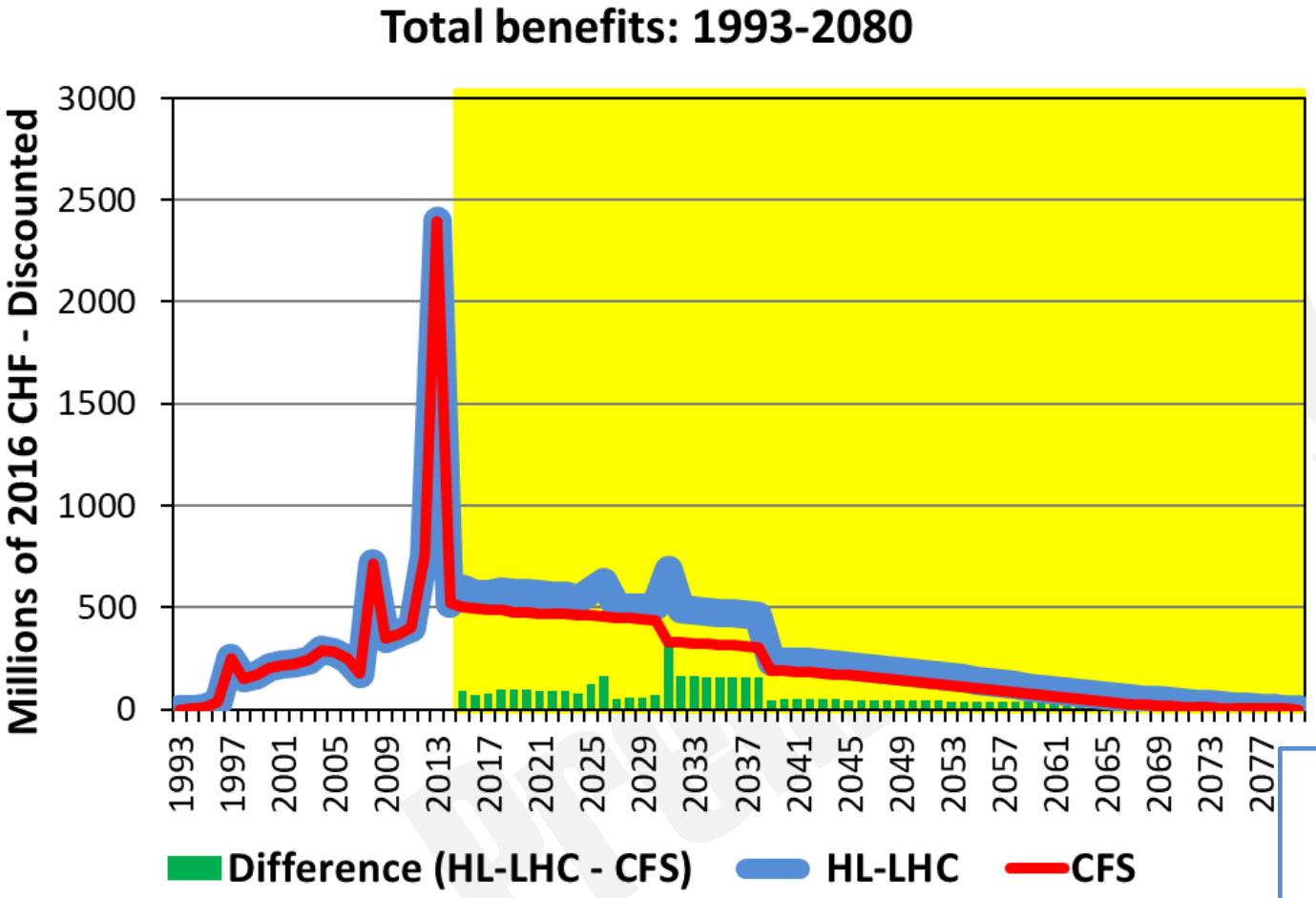
In 2016 the per capita contribution of the 415M taxpayers in Member States for CERN related discovery : was around 2.3 EUR each per year.

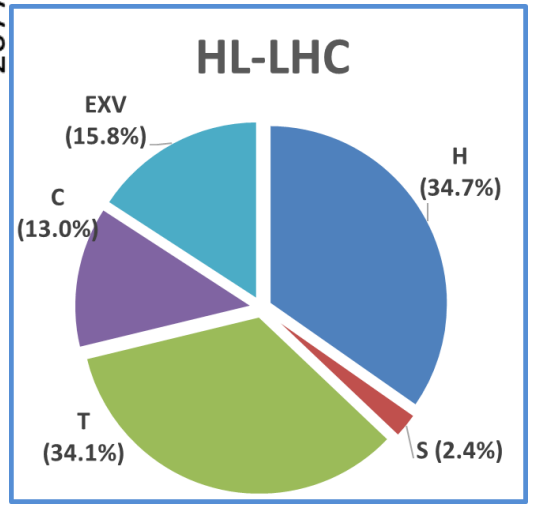
- Culture, science, environment are public goods and as such have an existence value reflected in the willingness to pay for them
- Median Annual per-capita WTP for the Royal theatre in Copenhagen: EUR 8 (DKK 60) [Hansen, 1997. J Cult. Ec., 21(1):1-28.

- WTP for LHC: contingent valuation experiment (FFS 2016).

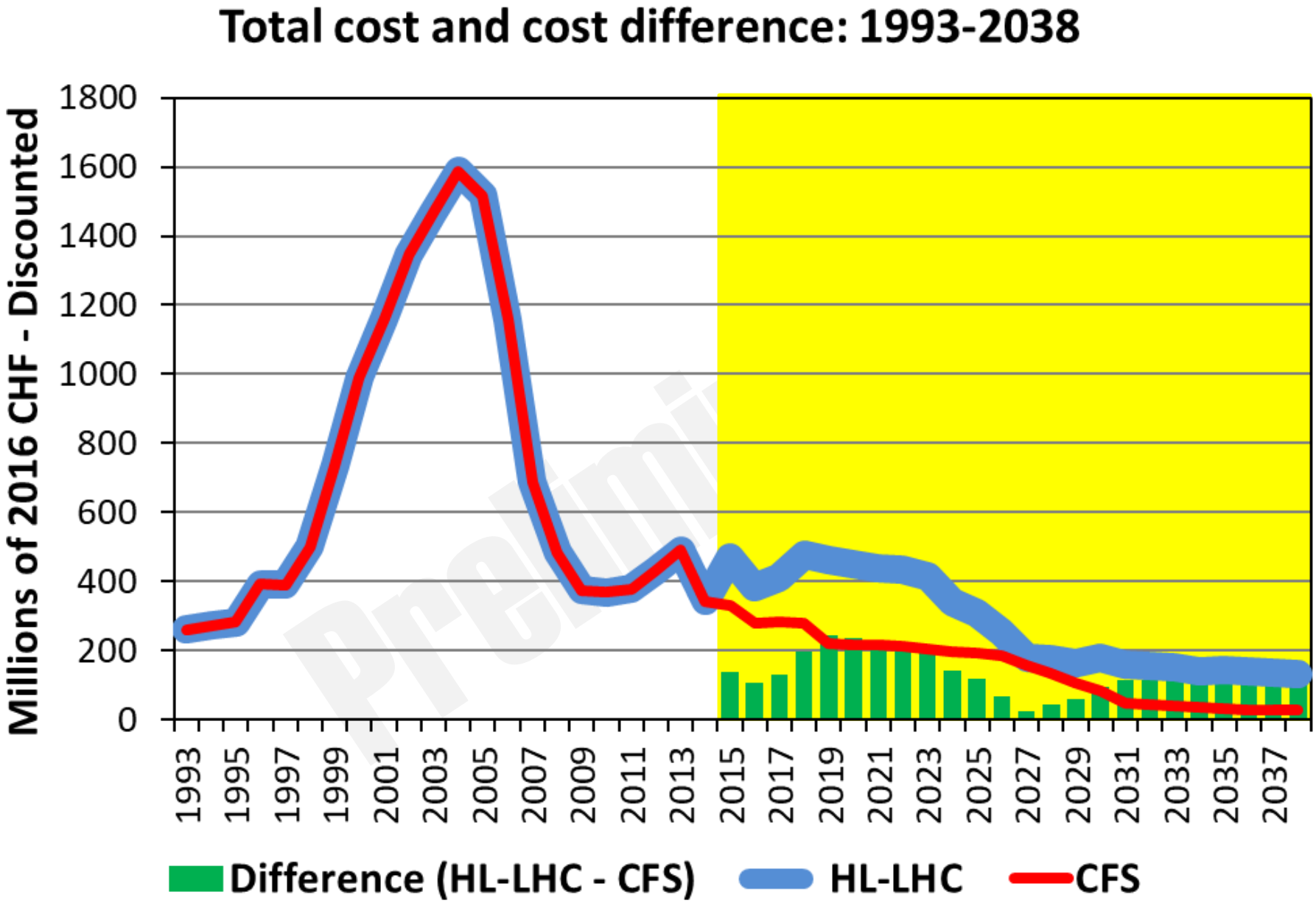


Benefits: dynamics and share of total

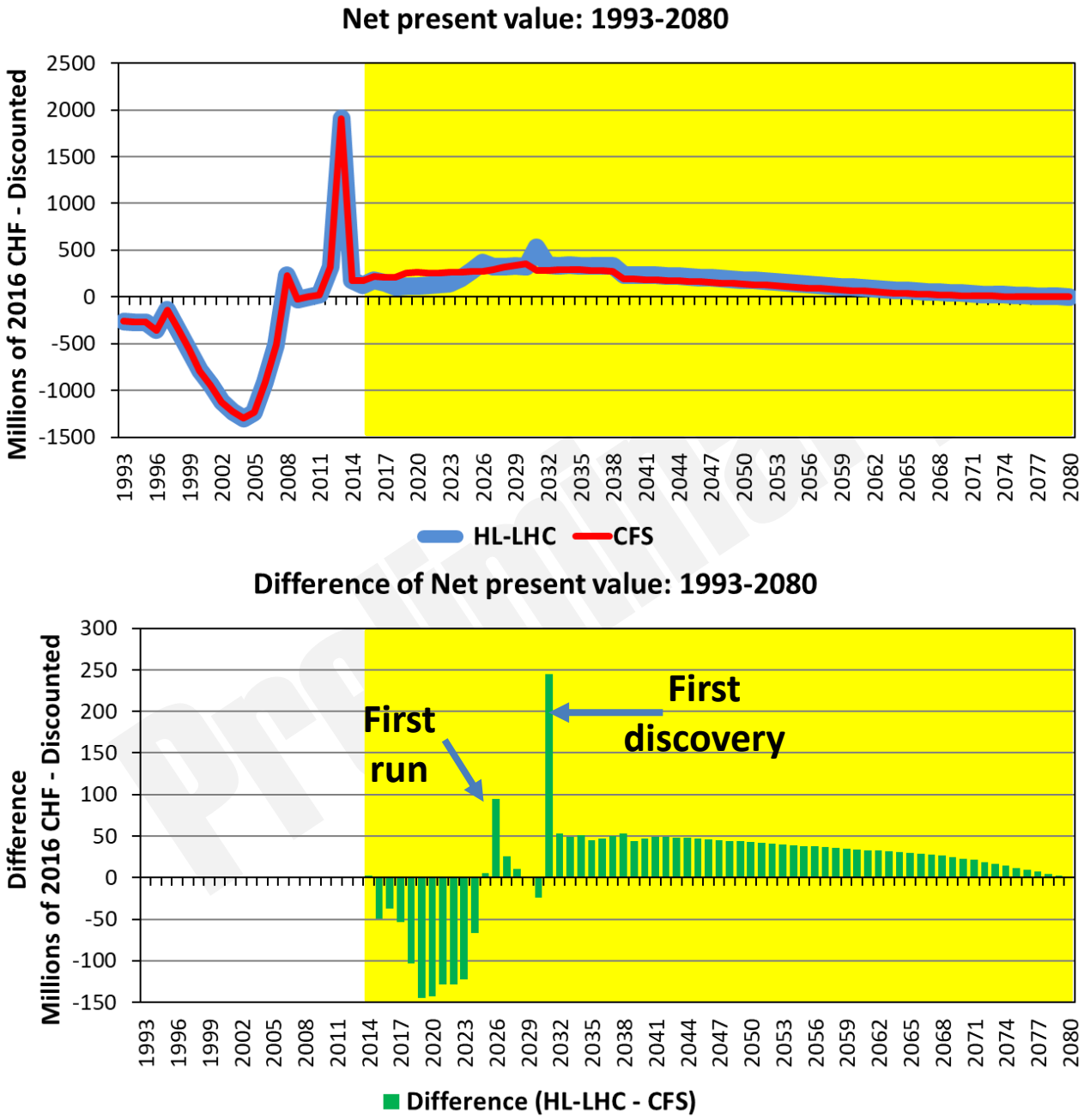




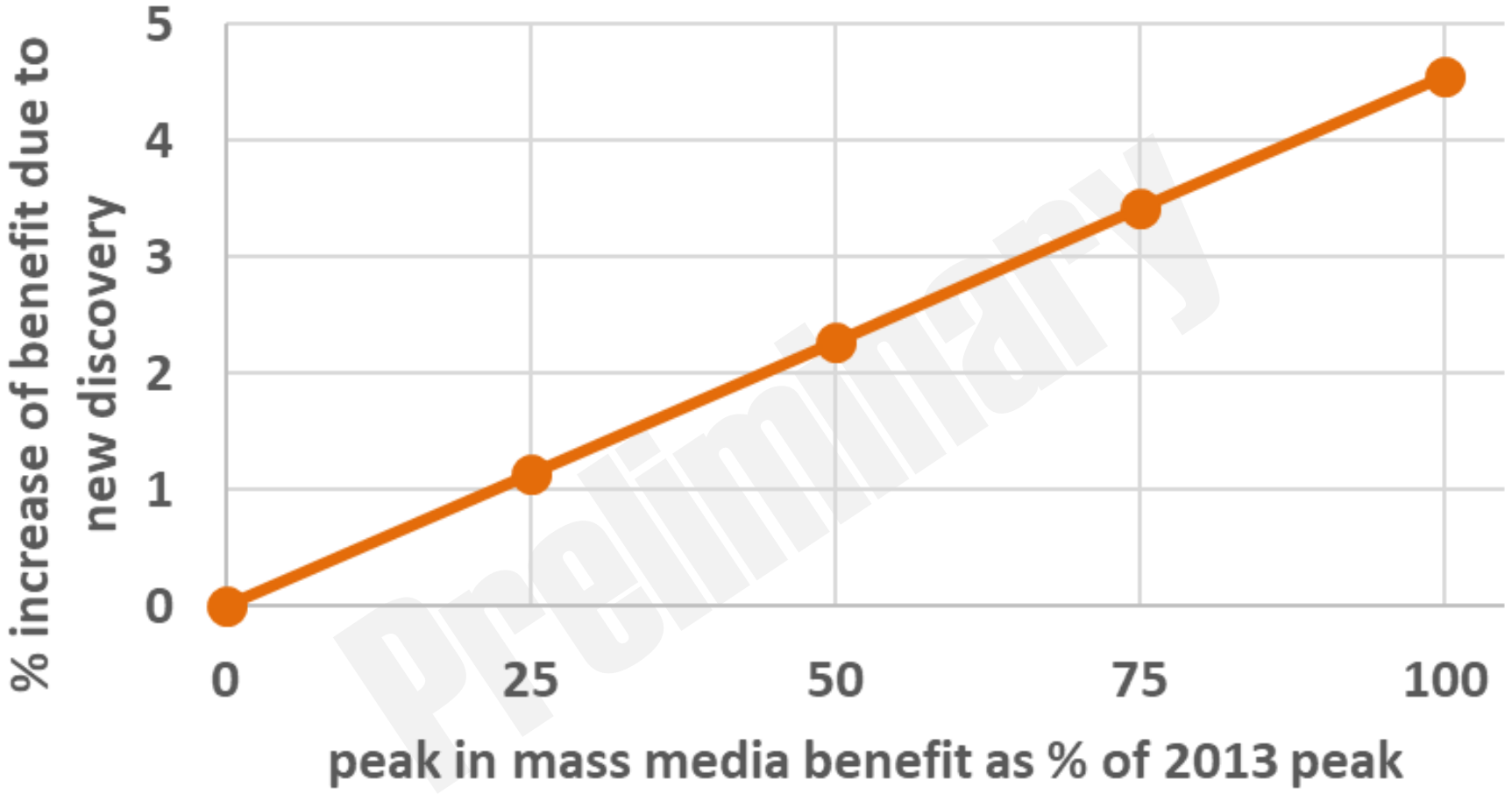
Total Costs


Total cost and cost difference: 1993-2038
Millions of 2016 CHF - Discounted
1800
1600
1400
1200
1000
800
600
400
200
0
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
Difference (HL-LHC - CFS)
HL-LHC
CFS

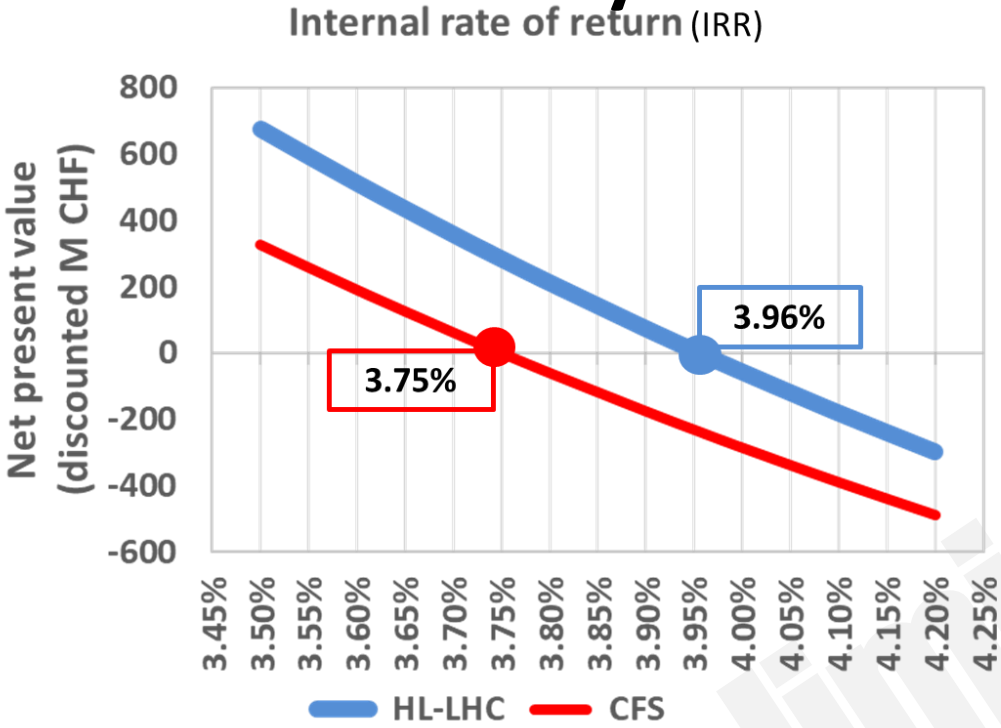
Net present value: 1993-2080



Sensitivity analysis with and without new discovery



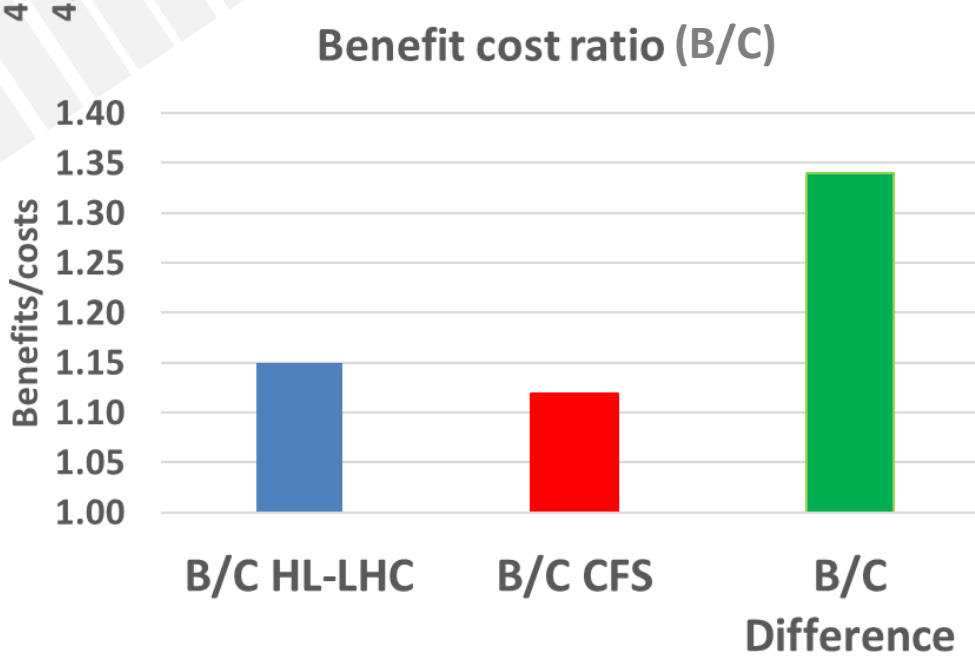
Cost-benefit analysis



$$NPV = \sum_t \frac{(B_t - C_t)}{(1+IRR)^t} = 0$$

Good news if:

- IRR>3%
- B/C > 1



Next steps

- Revision of the time profile of costs in both scenarios and risk analysis of LHC-HL costs
- More detailed study of intake of students and postdoc
- Refinement of the analysis of technological spillovers to firms
- Reconsideration of benefits from open software, given the data intensity of HL-LHC
- Risk analysis on the correlation between discovery, publications, and cultural effects
- Monte Carlo analysis of the NPV of both scenarios based on probabilities attached to several critical variables.

Thank you!

Work in progress… Stay tuned!

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