Findings from the HL-LHC programme

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SPECIAL WORKSHOP - "THE ECONOMICS OF SCIENCE“

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What do economists have to do with CERN?

or small science meets big science

- CERN and more generally Big Science Centres (BSCs) as ideal testing ground for theoretical and empirical economic models
  - BSCs activities generate unique data for empirical economists (e.g. procurement, staff, students, ICT, media coverage…)
  - Governance and procurement policies of BSCs are interesting topics in management studies
  - Innovation and breakthrough technologies arising from BSCs as driver of growth and business cycle fluctuations… macroeconomists do care!

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→Good economics leads to good policy decisions

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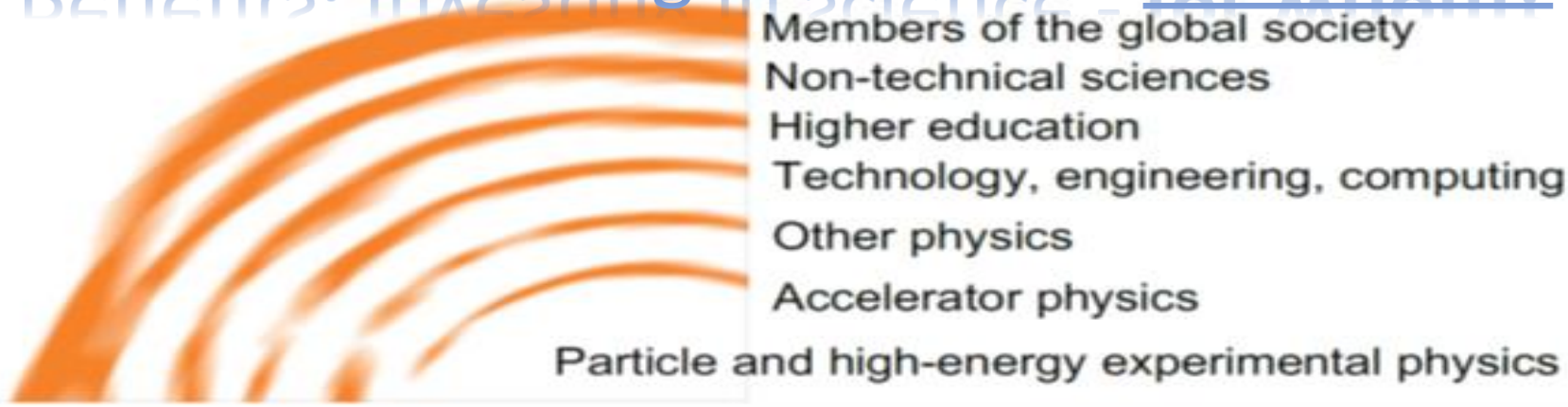
→Good economics leads to good policy decisions

→What can BSCs do to help improving economic analyses?

Why social Cost Benefit Analysis (CBA)?

Benefits: Investing in science - **for whom?**



Source: http://cds.cern.ch/record/2653673

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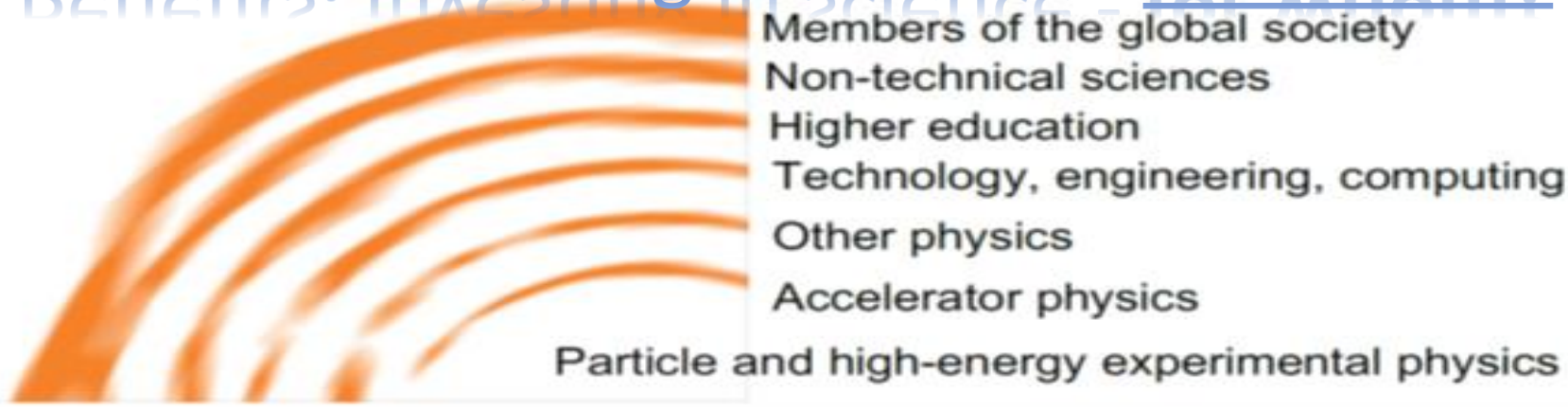

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Social Cost Benefit Analysis (CBA)

- Quantify and compare societal costs & benefits of a project/research infrastructure (RI) over its entire lifespan
- Assess uncertainty of benefits and costs with Monte Carlo methods

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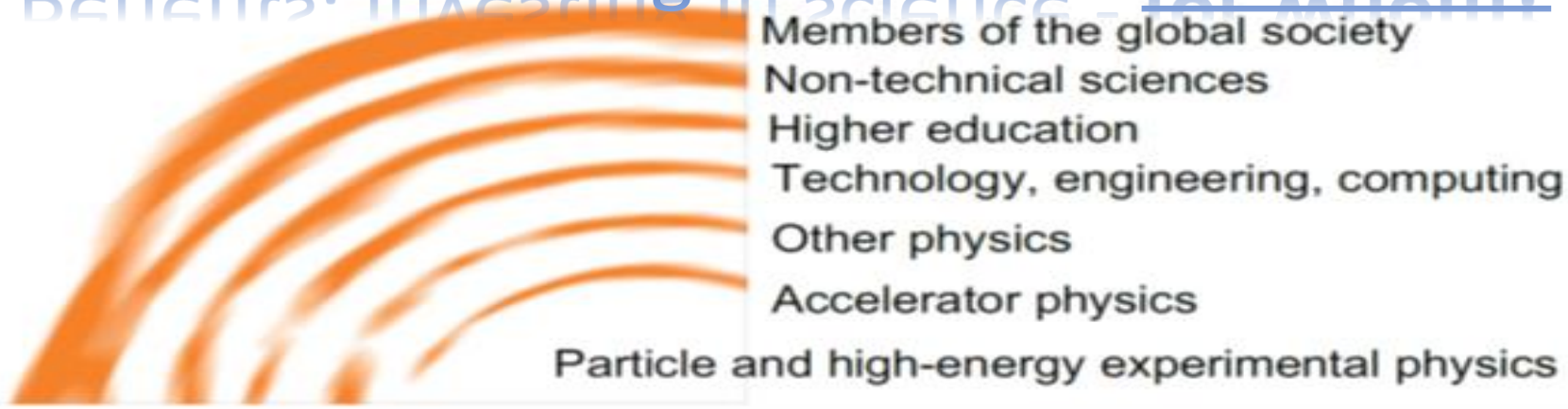

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Social Cost Benefit Analysis (CBA)

- Quantify and compare societal costs & benefits of a project/research infrastructure (RI) over its entire lifespan
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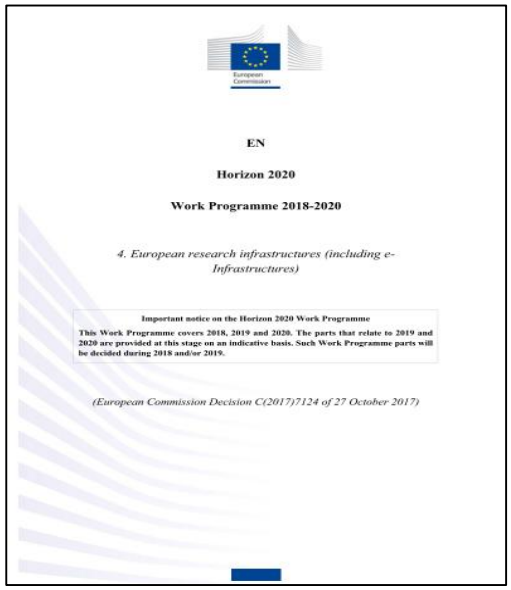
Inform policy makers

- NOTE: CBA does not inform on the scientific merits of different RIs!!

Why do CERN and BSCs care about CBA?



EN

Horizon 2020

Work Programme 2018-2020

4. European research infrastructures (including e-Infrastructures)

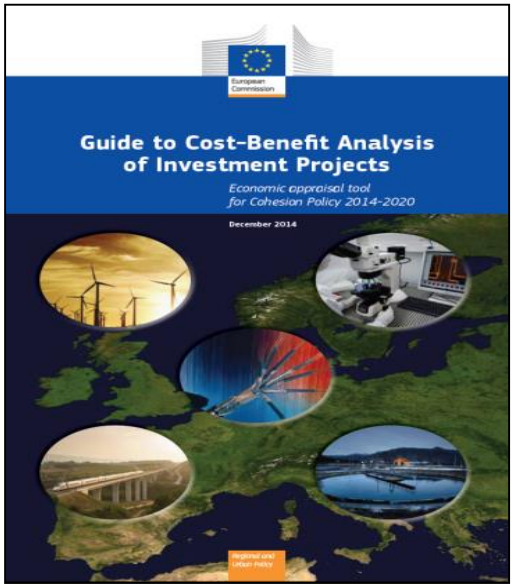
Important notice on the Horizon 2020 Work Programme

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

CBA of the HL-LHC programme

Background

- Florio, Forte and Sirtori (FFS, 2007) carried out a CBA of the LHC
- Bastianin and Florio (2018) extended this analysis to HL-LHC
  - Several reports illustrate the methodology underlying the CBA and the estimation of each benefit category
  - A final report overviews how the CBA methodology could be applied to different FCC scenarios
- NOTE: thanks to people at CERN, UNIMI, CSIL for the background work, support and information

CBA of the HL-LHC programme

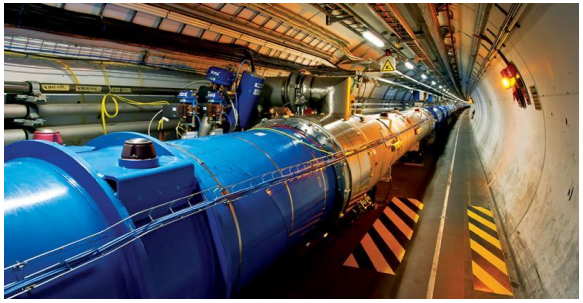
Baseline & counterfactual scenarios

- 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 the HL-LHC programme

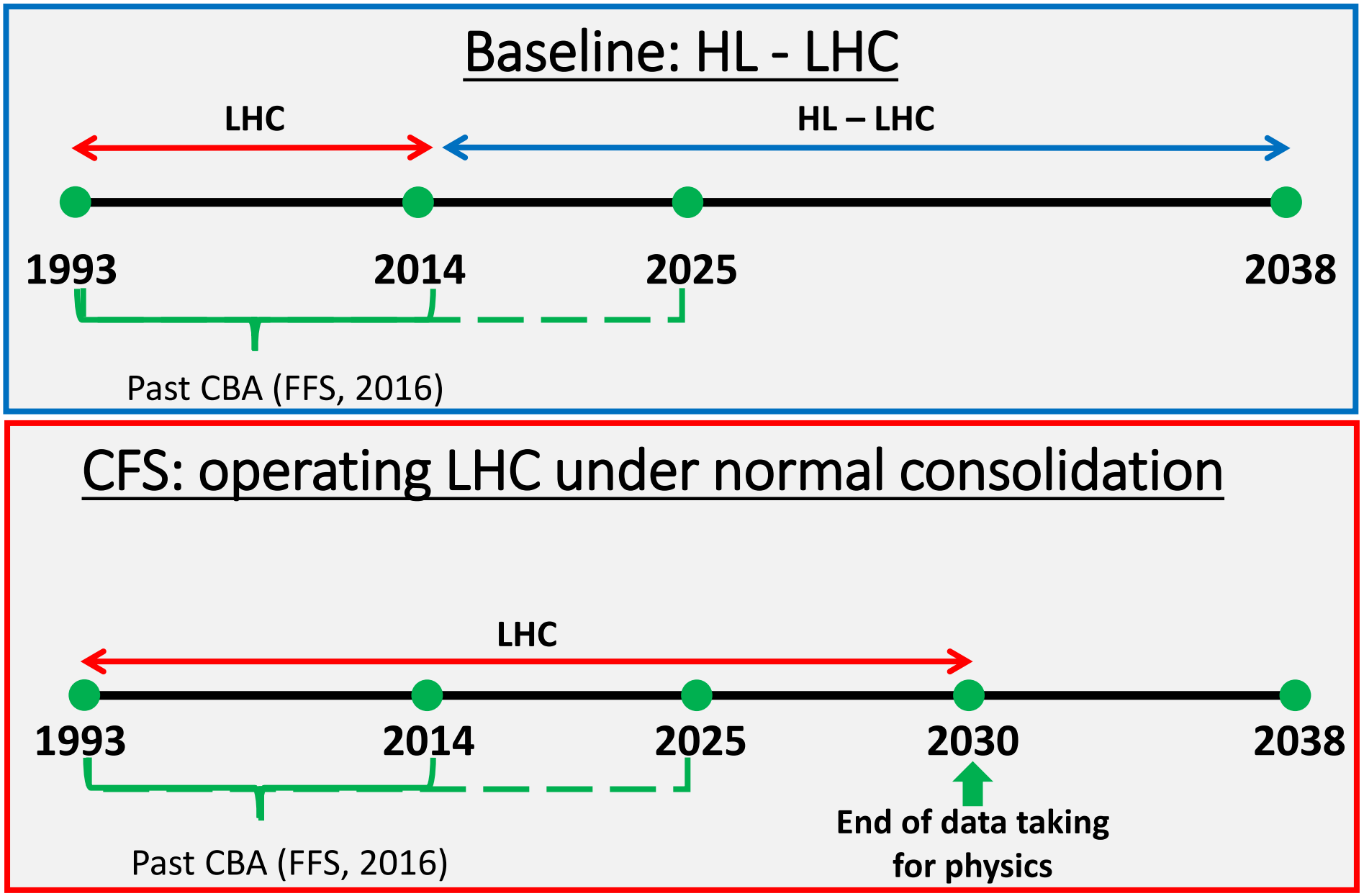
The counterfactual scenario

- 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 the HL-LHC programme

Timeline



CBA methodology

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

- 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

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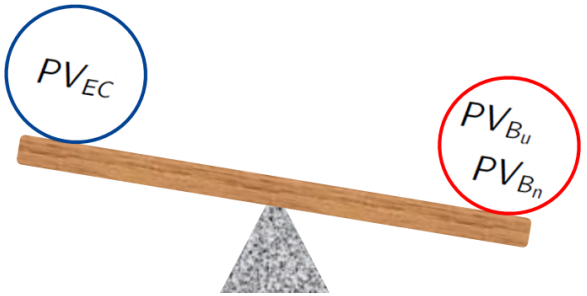
$\Longrightarrow$ RI passes CBA if:

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



CBA methodology

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

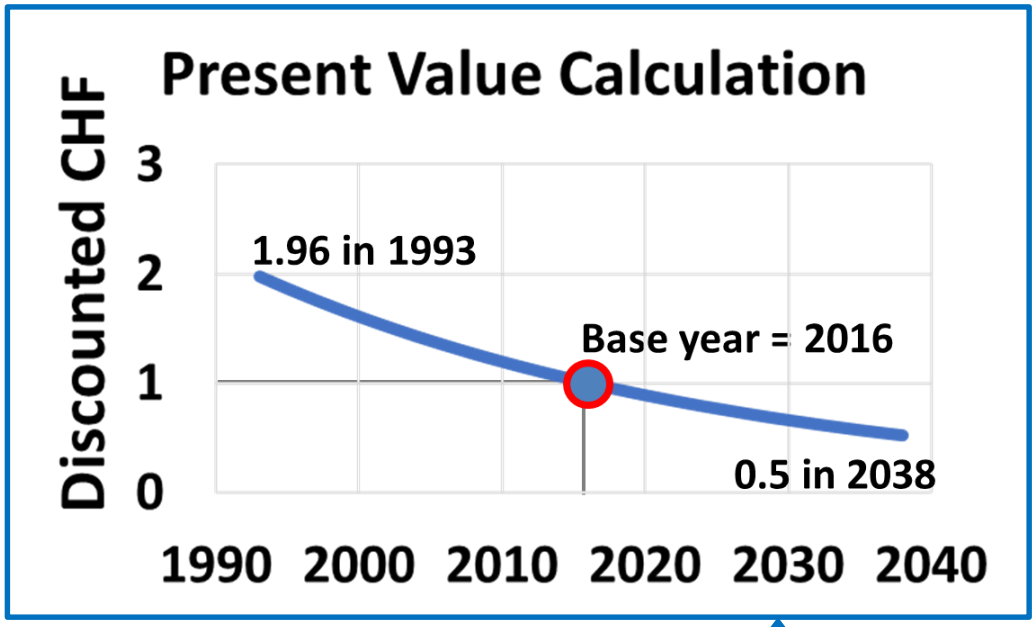
$$NPV_{HL\text{-}LHC} > NPV_{CFS}$$

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

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

- Base year: 2016 (i.e. discounting and inflation adjustments)

CBA methodology



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- **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)

Social benefits of the HL-LHC programme

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

arXiv.org

Scientists (S): 1993-2063

- Preprints & publications

Early Stage Researchers (H): 1993-2080

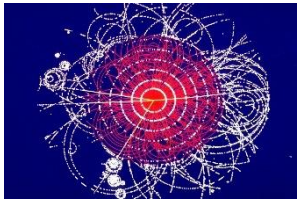
- Human capital formation

Firms (T) : 1993-2038

- Technological spillovers and free ICT

General public (C): 1993-2038

- Cultural effects of outreach



Taxpayers (EXV): 1993-2038

- Public good value of science

Results

Cost Benefit Analysis

Discounted MCHF 2016	HL-LHC	%	CFS	%	Difference	%
Total cost	22292		19175		3117	
Total Benefit	25774		20442		5332	
Human Capital	8545	**33%**	6302	**31%**	2243	**42%**
Publications	613	**2%**	322	**2%**	290	**5%**
Technological Spillovers	10187	**40%**	8233	**40%**	1954	**37%**
- ICT	6029	*23%*	5591	*27%*	438	*8%*
- Hi-tech Suppliers	4158	*16%*	2642	*13%*	1516	*28%*
Cultural Benefits	3319	**13%**	3028	**15%**	291	**5%**
Public good value	3110	**12%**	2557	**13%**	553	**10%**
NPV	3481		1267		2215	
B/C ratio	1.16		1.07		1.71	

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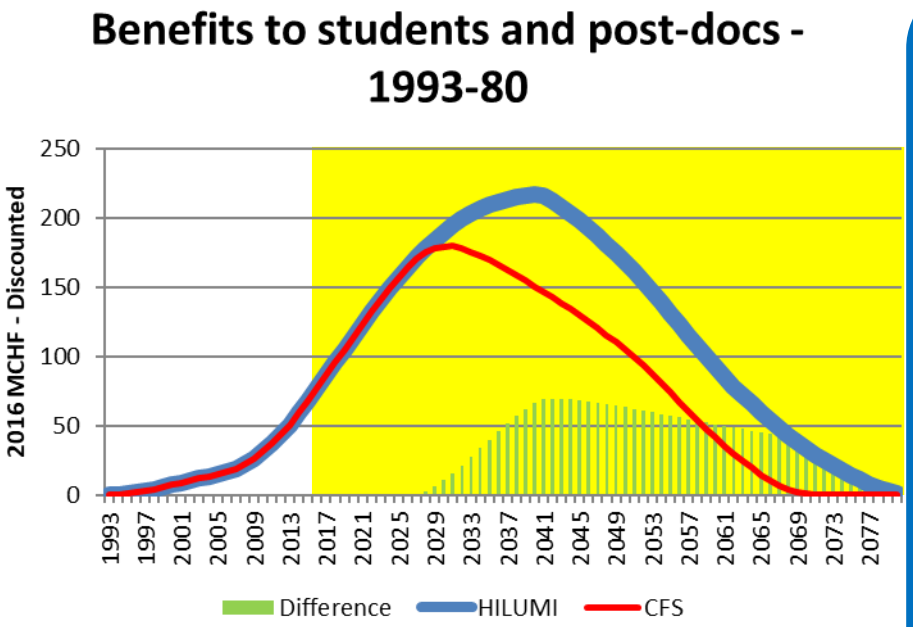
Benefits for early stage researchers

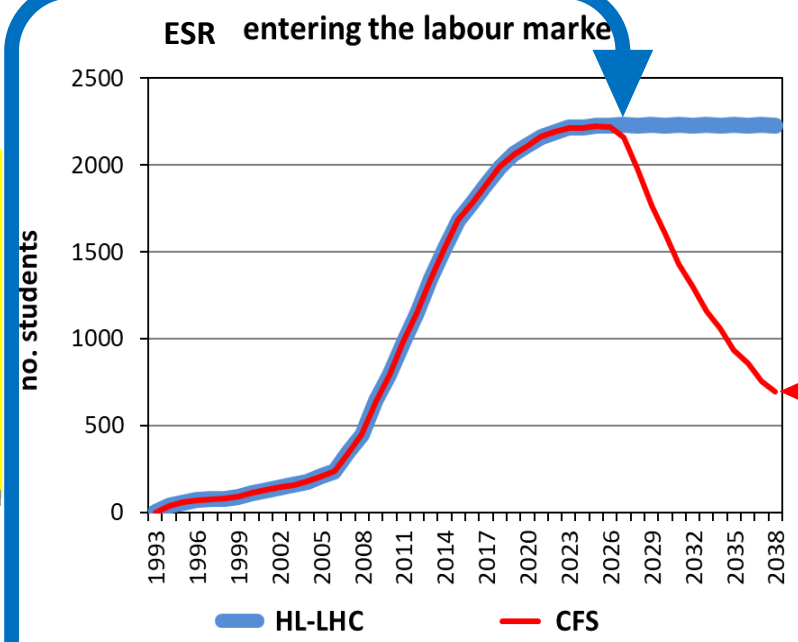
$$\sum_{t}^{\tau}\sum_{i}^{I}\left[\text{Number of students } N_i \times \text{Incremental salary } Salary_{i,t}\right] \times \text{Discounting effect} = \text{Social value of human capital fromation}$$

Where i identify the professional sector considered

The incremental salary depends on both the professional sector and the career level, which in turn depends on time

Benefits for early stage researchers (ESR)





- HL-LHC: by 2025 no. ESR = full capacity:
  - constant for collaborations
  - Decreasing for CERN
- CFS: without major technological improvement, loss of attractiveness for ESR

Benefits for firms

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

$$PROC_t \times Share^{HT\ PROC} \times S^{Mult} \times \Delta\Pi$$

- HL-LHC requires a substantial revision of current software to manage and store an increased experimental data flow (**very conservative**)
  - ROOT: constant benefit, no improvements
  - GEANT4: constant benefit, no improvements
  - Other free ICT: only for HL-LHC from 2025

CBA meets Monte Carlo

Select a statistical distribution for each parameter underlying estimated social costs and benefits and draw from them

Example:

$$PROC_t \times Share^{HT\ PROC} \times S^{Mult} \times \Delta\Pi$$

$$\Delta\Pi \sim N(\mu,\sigma^2)$$

Note: need assumptions or estimates of parameters

CBA meets Monte Carlo

Select a statistical distribution for each parameter underlying estimated social costs and benefits and draw from them

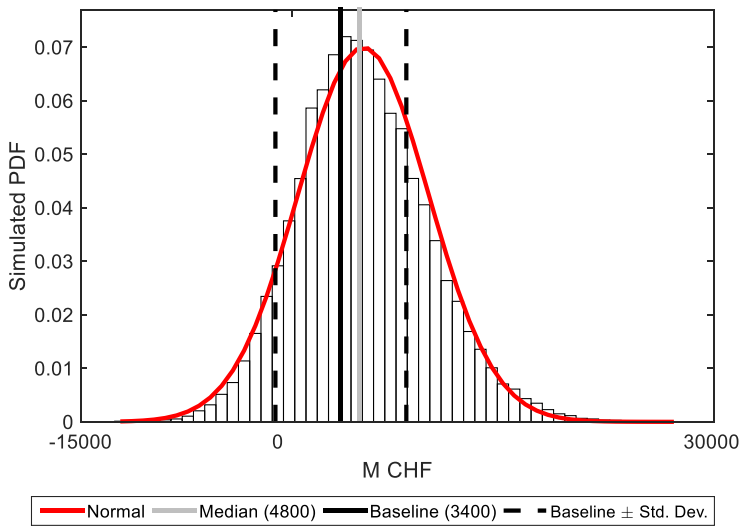
Repeat the CBA for a large number of draws

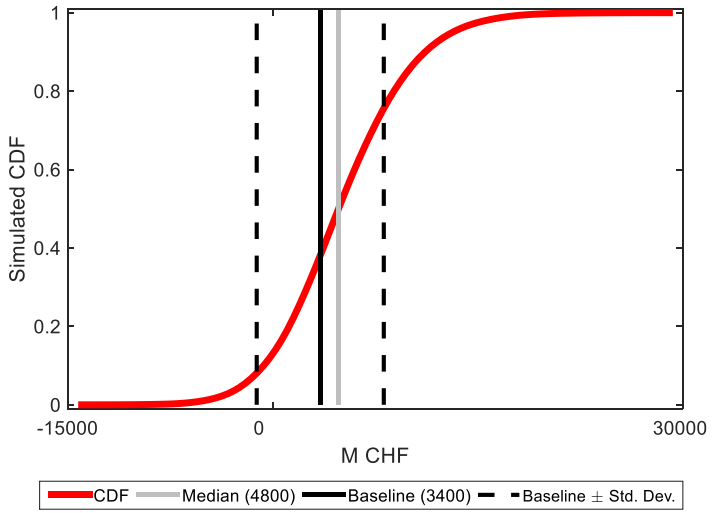
Inference about CBA output of interest

Monte Carlo analysis of the HL-LHC scenario

	Variable	Distribution	Parameters				Source
1	**Discounted total cost**	Triangular	baseline		-3%	8%	Derived from CERN (Alfred's File)
	Total present benefit of human capital formation						
2	Salary bonus for job effect	Triangular	2.5%		2.0%	3.0%	FFS
3	Total number of students	Triangular	0%		-15%	15%	FFS
	Total present benefit of Software						
4	Number of ROOT users	Triangular	0%		-20%	20%	FFS
5	Avoided cost to get ROOT (CHF/year)	Triangular	1754		1170	2339	FFS
6	Number of years of use	Trapezoidal	0		3	10 20	FFS
7	Avoided cost to get GEANT (non discounted)	Triangular	baseline		-30%	30%	FFS
8	Importance of new ICT (as % of root 1997 peak)	Triangular	2		1	45	Own assumption (45 makes benefit proportional to that of GEANT)
	Total present benefit HT suppliers						
9	Share of high-tech procurement value over total procurement - CERN (1993-2014)	Triangular	35%		34%	75%	FFS
10	Share of high-tech procurement value over total procurement - Collaborations (1993-2014)	Triangular	58%		55%	90%	FFS
11	Economic utility/sales ratio	Triangular	3		1.4	4.2	FFS
12	EBITDA margin	Normal	mean = 13%	std. dev. = 10%			FFS
	Scientific publications						
13	% peak in 2031 compared to past peak in benefits	Triangular	1		0.1	1	FFS
	Existence Value						
14	Average WTP for LHC (at least > 0)	Triangular	1.53		0.1	2	
15	**Cultural Benefits**	Triangular	Baseline		-20%	20%	

Monte Carlo analysis of the HL-LHC scenario





Simulated NPV - Descriptive Statistics	
CBA baseline	3,482
mean	5,076
median	4,809
Std. Dev.	4,647
min	-12,575
max	27,371
Prob(NPV $\leq$ 0)	0.13

Scenario analysis

Simulated NPV - Descriptive Statistics	
CBA - pessimistic cost scenario	1,880
mean	3,750
median	3,482
Std. Dev.	4,619
min	-13,714
max	26,771
Prob(NPV ≤ 0)	0.20

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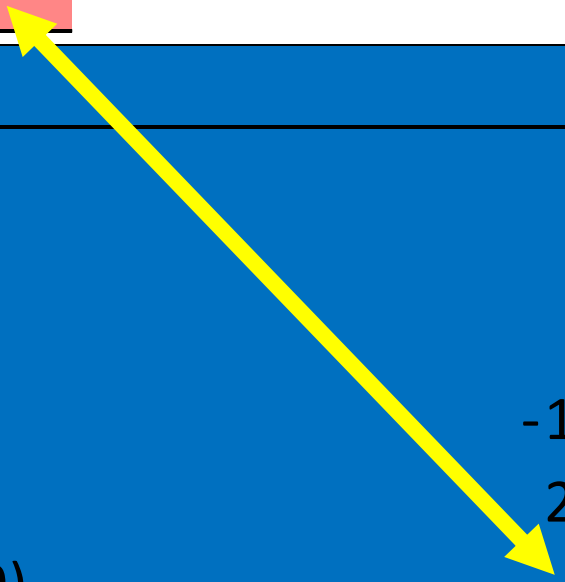

What can BSCs do to improve economic analyses?

- CERN has been very collaborative with us providing a lot of data and information
- With these data we have run the CBA and several empirical analyses
  - Empirical evidence points to the existence of beneficial effects for firms (e.g. incremental profits, innovation push), wage effects for past-students and researcher…
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- Other benefits are harder to estimate, but we have soft-evidence of them (e.g. ICT)
- More and better data are needed for improving inferences about CBA results, advancing the methodology and ultimately to provide better information to decision makers