SPS Beam Dump Facility Project Introduction & SHiP

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on behalf of the BDF Project team

CERN | EN ENGINEERING DEPARTMENT

Outlook

- Introduction to Physics Beyond Colliders
- Beam Dump Facility within PBC
- The SHiP Experiment
- BDF design and main components
- Current status of the studies and perspectives
- Conclusions

Three main scientific pillars

Full exploitation of the LHC → over the period of this MTP:

- ❑ successful Run 2, LS2, and Run 3 start-up
- ❑ construction and installation of LIU; on-track construction of HL-LHC

Scientific diversity programme serving a broad community:

- ❑ ongoing experiments and facilities at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE)
- ❑ participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through CERN Neutrino Platform

Preparation of CERN's future:

- ❑ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ❑ design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- ❑ future opportunities of diversity programme (new): "Physics Beyond Colliders" Study Group

Important milestone: update of the European Strategy for Particle Physics (ESPP): ~ 2019-2020
→ 10-year view has uncertainties beyond 2020 for part of programme other than LHC upgrade

F. Gianotti, Scientific Policy Committee, May 2016

Physics Beyond Collider

"Physics Beyond Colliders" Study Group established in March 2016

Mandate
Explore opportunities offered by the (very rich) CERN accelerator complex to address outstanding questions in particle physics through projects:

- ❑ complementary to high-energy colliders (studied at CERN: HE-LHC, CLIC, FCC)
  → we know there is new physics, we don't know where it is → we need to be as broad as possible in our exploratory approach
- ❑ exploiting the unique capabilities of CERN accelerator complex and infrastructure and complementary to other efforts in the world:
  → optimise the resources of the discipline globally

⬇

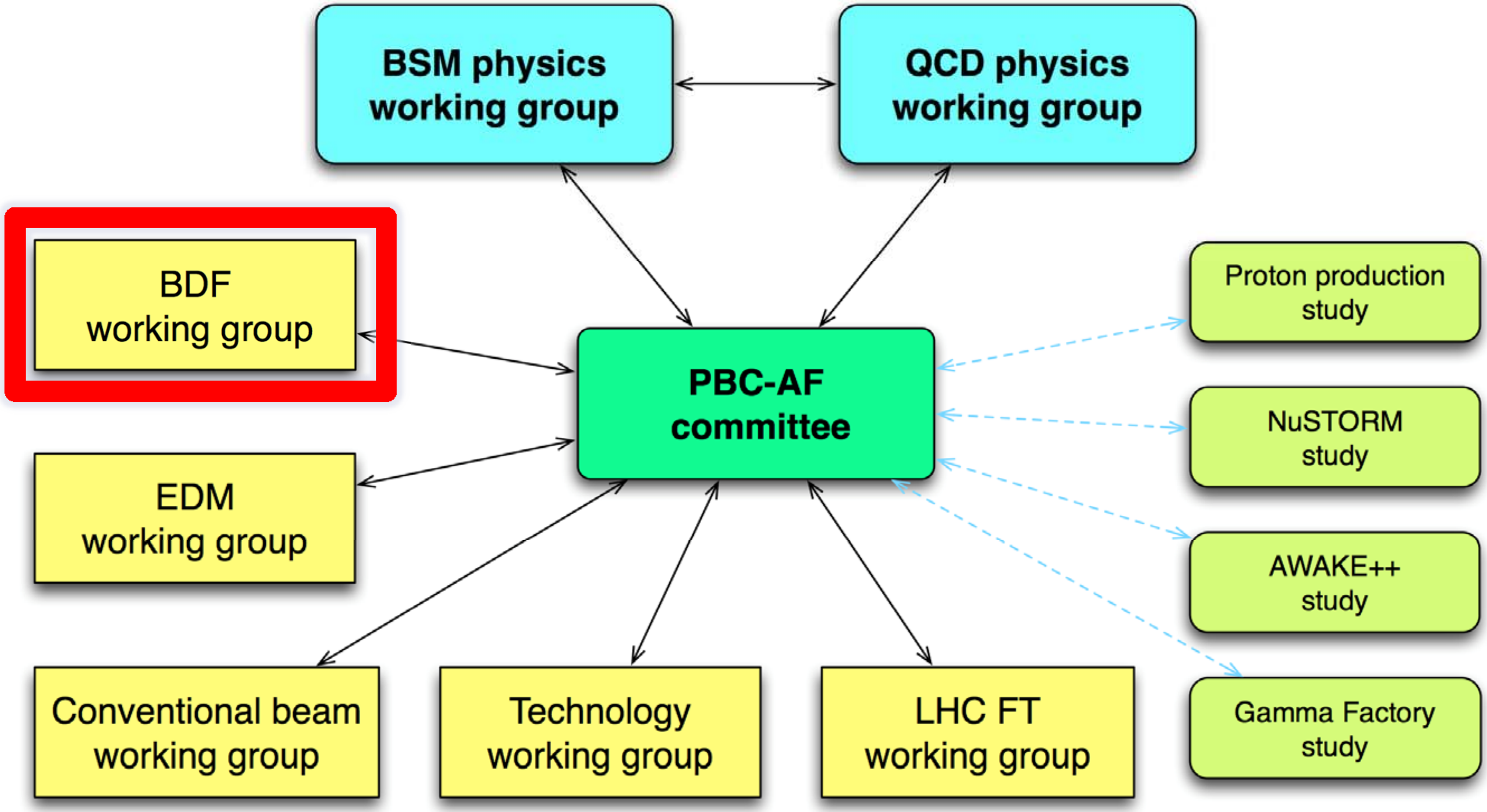
Enrich and diversify CERN's future scientific programme

Goal is to involve interested worldwide community, and to create synergies with other laboratories and institutions in Europe (and beyond).
Note: interesting ideas may emerge from these studies which do not need to be realised at CERN.

- ❑ Overall coordinators: Joerg Jaeckel (Heidelberg; theory), Mike Lamont (CERN; accelerator), Claude Vallée (CPPM and DESY; experimental physics)
- ❑ Kick-off meeting 6-7 September 2016
- ❑ Final report by end 2018 → in time for update of European Strategy

F. Gianotti, PBC kick-off workshop, September 2016

PBC organisation



Hidden sector – "discovery" physics

- Well known that Standard Model, despite its great successes, is still **incomplete**:
  - Neutrino masses and oscillations
  - Dark matter, *absent in SM*
  - Baryogenesis, *absent in SM*
  - Different anomalies: muon magnetic moment, LSND,...
- **Energy scale for new physics is unknown**

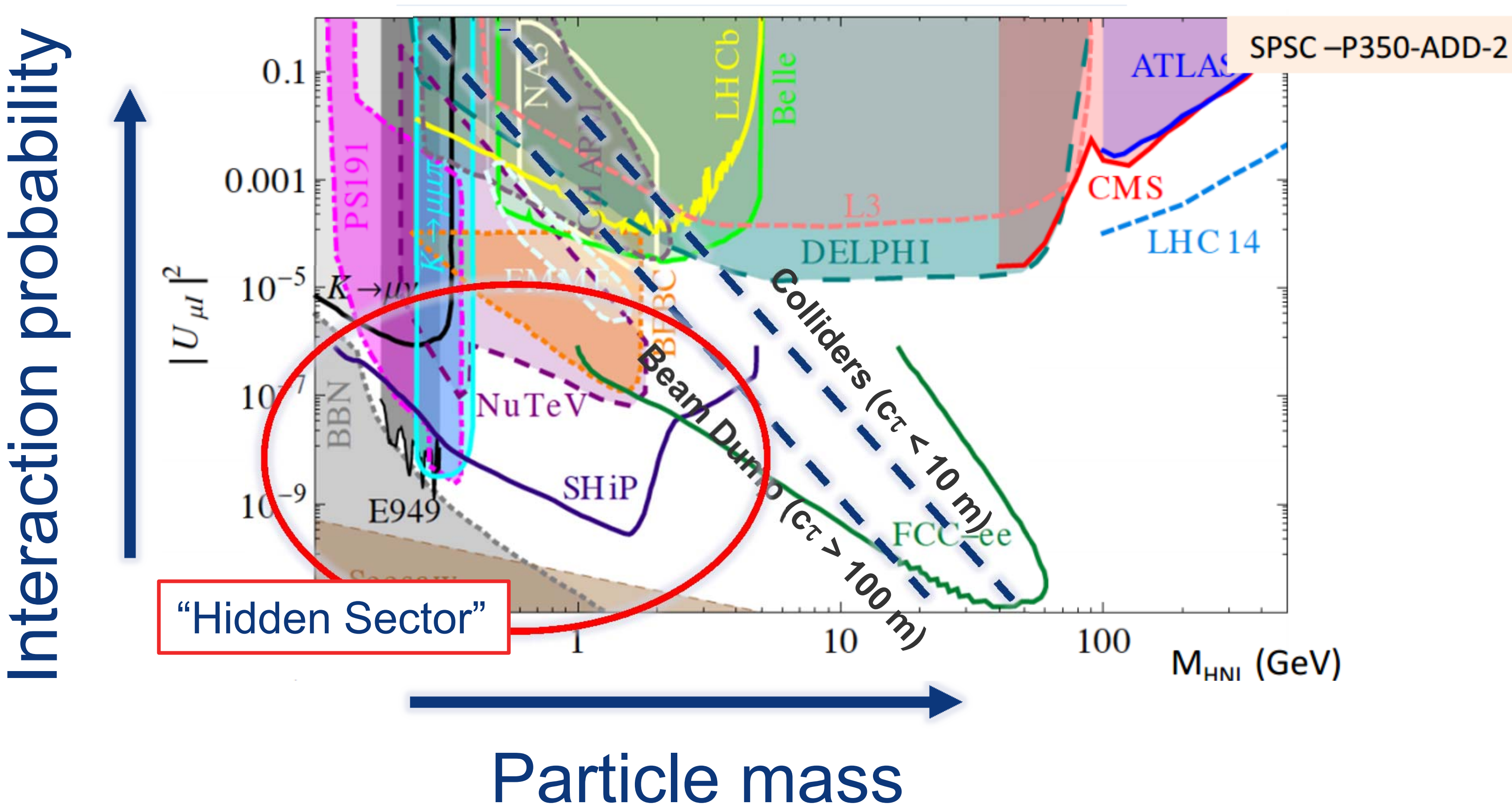
Hidden Sector experimental requirements

- **Cosmologically interesting and experimentally accessible m_{HS} ~ O(MeV – GeV)**
  - Hidden particle production in π, K, D, B, decays, coupling to photons → High A and Z target
- **Production and decay rates are very suppressed relative to SM**
  - Production branching ratios ~O(10^{-10}) → Largest possible number of protons
  - Long-lived objects → Large decay volume
  - Travel unperturbed through ordinary matter → Allows filtering out background → Background suppression is a key aspect of the facility

Courtesy: SHiP Collaboration

Beam Dump Facility

What can be done in a Beam Dump Facility that cannot be done in a collider?



SHiP experimental proposal

- Proposition of beam dump experiment at CERN SPS with **~2*10^{20} protons on target @400 GeV/c**
  - More than 10^{17} D mesons`
  - More than 10^{20} bremsstrahlung photons
  - Equivalent luminosity ~10^{46} cm^2 vs. 10^{42} cm^2 for HL-LHC
- ❑ **~O(1000)** improvement over any previous searches
- High energy (400 GeV/c) to increase c quark cross-section
- Crucial design parameters: **residual ν and μ fluxes**
  - Reduction of neutrinos from light meson decays
    - **Dense target/dump**
  - Short-lived resonances generate ~10^{10} μ/spill
    - **Active muon shield** – ~90 Tm

Physics Program

- Direct detection through decay - Full reconstruction and identification

Signature	Physics	Backgrounds	Cuts
$\pi^-\mu^+, K^-\mu^+$	HNL,NEU	RDM, $K_L^0 \to \pi^-\mu^+\nu_\mu$	IP,TI,PID($\mu\pi$) P,NT
$\pi^-\pi^0\mu^+$	HNL($\to \rho^-\mu^+$)	$K_L^0 \to \pi^-\mu^+\nu_\mu(+\pi^0)$, $K_L^0 \to \pi^-\pi^+\pi^0$	P,IP,NT,TI,P,PID($\pi\mu$)
π^-e^+, K^-e^+	HNL, NEU	$K_L^0 \to \pi^-e^+\nu_e$	P,IP,NT
$\pi^-\pi^0e^+$	HNL($\to \rho^-e^+$)	$K_L^0 \to \pi^-e^+\nu_e$, $K_L^0 \to \pi^-\pi^+\pi^0$	P,IP,NT,TI,PID(πe)
$\mu^-e^+ + p^{miss}$	HNL,HP($\to \tau\tau$)	$K_L^0 \to \pi^-\mu^+\nu_\mu$, $K_L^0 \to \pi^-e^+\nu_e$	P,NT, PID($\pi\mu$, πe)
$\mu^-\mu^+ + p^{miss}$	HNL,HP($\to \tau\tau$)	RDM, $K_L^0 \to \pi^-\mu^+\nu_\mu$	TI,P,NT, PID($\pi\mu$)
$\mu^-\mu^+$	DP,PNGB,HP	RDM, $K_L^0 \to \pi^-\mu^+\nu_\mu$	TI,IP,P,NT,PID($\pi\mu$)
$\mu^-\mu^+\gamma$	CS	$K_L^0 \to \pi^-\pi^+\pi^0$, $K_L^0 \to \pi^-\mu^+\nu_\mu(+\pi^0)$	P,IP,NT, PID($\pi\mu$),TI,VP
$e^-e^+ + p^{miss}$	HNL,HP	$K_L^0 \to \pi^-e^+\nu_e$	P,NT, PID(πe)
e^-e^+	DP,PNGB,HP	$K_L^0 \to \pi^-e^+\nu_e$	P,IP,NT, PID(πe)
$\pi^-\pi^+$	DP,PNGB,HP	$K_L^0 \to \pi^-\mu^+\nu_\mu$, $\to \pi^-e^+\nu_e$, $\to \pi^-\pi^+\pi^0$, $\to \pi^-\pi^+$	P,NT,PID($\mu\pi$),IP, PID($e\pi$),IP,POA,IP
$\pi^-\pi^+ + p^{miss}$	DP,PNGB, HP($\to \tau\tau$), HSU,HNL($\to \rho^0\nu$)	$K_L^0 \to \pi^-\mu^+\nu_\mu$, $\to \pi^-e^+\nu_e$, $\to \pi^-\pi^+\pi^0$, $\to \pi^-\pi^+$, $K_S^0 \to \pi^-\pi^+$,$\Lambda \to p\pi$	
K^+K^-	DP,PNGB, HP	$K_L^0 \to \pi^-\mu^+\nu_\mu$, $\to \pi^-e^+\nu_e$, $\to \pi^-\pi^+\pi^0$, $\to \pi^-\pi^+$,$K_S^0 \to \pi^-\pi^+$,$\Lambda \to p\pi$	P,NT, PID($\pi\mu$, πe),IP
$\pi^+\pi^-\pi^0$	DP,PNGB,HP, HNL($\eta\nu$)	$K_L^0 \to \pi^-\pi^+\pi^0$	P,IP,NT
$\pi^+\pi^-\pi^0\pi^0$	DP,PNGB,HP	$K_L^0 \to \pi^-\pi^+\pi^0(+\pi^0)$	P,IP,NT,TI
$\pi^+\pi^-\pi^0\pi^0\pi^0$	PNGB($\to \pi\pi\eta$)	–	–
$\pi^+\pi^-\gamma\gamma$	PNGB($\to \pi\pi\eta$)	$K_L^0 \to \pi^-\pi^+\pi^0$	P, IP, NT,M($\gamma\gamma$)
$\pi^+\pi^-\pi^+\pi^-$	DP,PNGB,HP	–	–
$\pi^+\pi^-\mu^+\mu^-$	HSU	–	–
$\pi^+\pi^-e^+e^-$	HSU	–	–
$\mu^+\mu^-\mu^+\mu^-$	HSU	–	–
$\mu^+\mu^-e^+e^-$	HSU	–	–
e-shower	LDM/ WIMP	ν interactions	–
etc..			

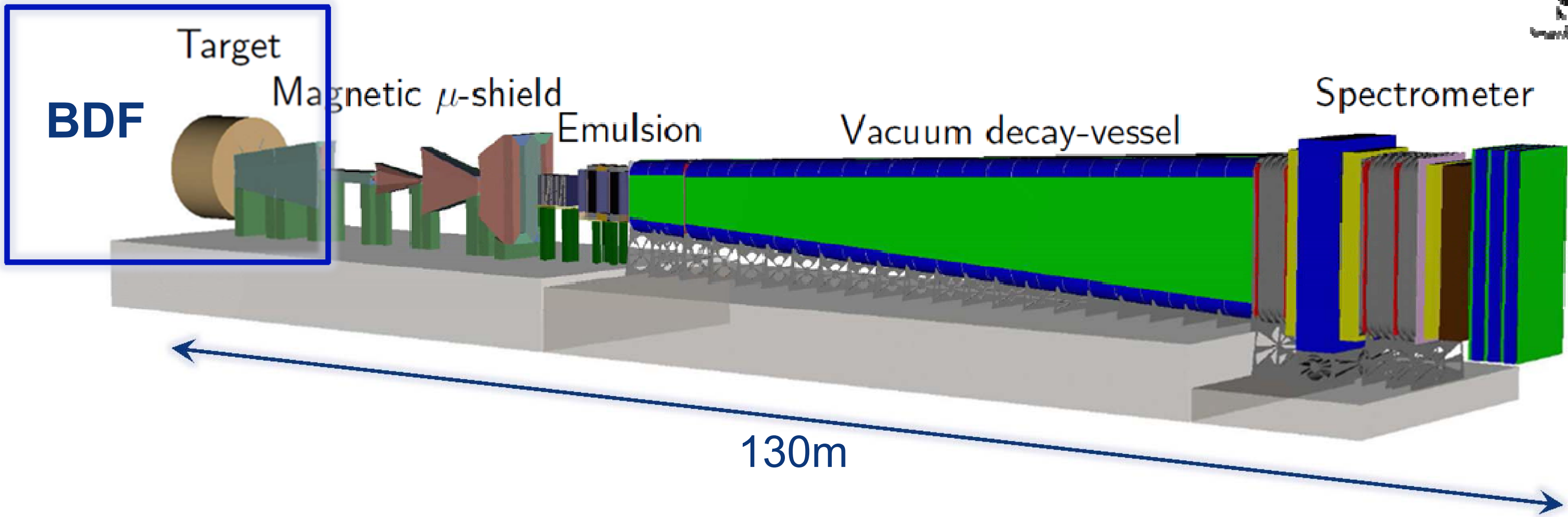
arXiv:1504.04855

- Signals: HNL=Heavy Neutral Lepton, NEU=neutralino, DP=Dark Photon, PNGB=Pseudo-Nambu Goldston Boson, HP=Higgs Portal, CS=Chern-Simons, HSU=Hidden SUSY, LDM=Light Dark Matter
- Background: RDM=random di-muons from the target
- Cuts: IP=impact parameter at the target, CPV= charged particle veto, NT=neutrino interaction tagger, VP= photon veto (i.e. if there is a photon around), TI=timing cuts with timing detector, P=total momentum cuts of the daughters, POA=1 particle outside acceptance, PID($\mu\pi$)=probability that a μ is misidentified as π or kaon.

- Indirect detection through scattering off atomic electrons or nuclei

Courtesy: SHiP Collaboration

SHiP Comprehensive Design Phase



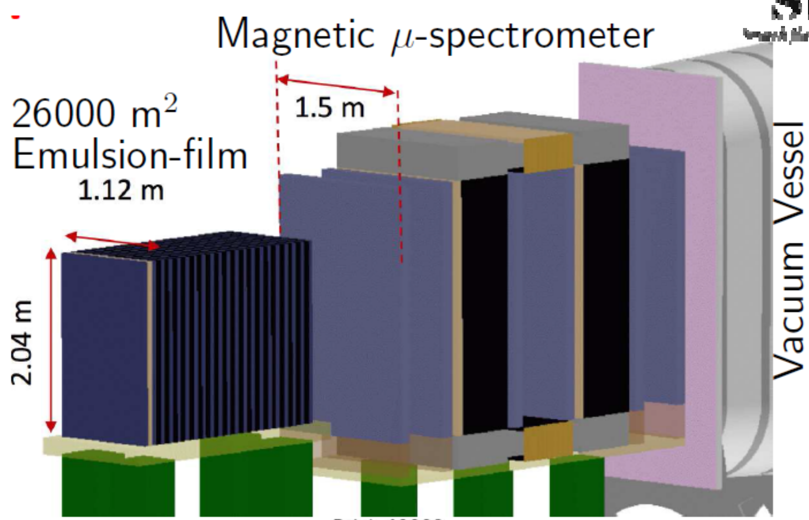
- SHiP is being re-optimized compared to Technical Proposal:
  - ~20 m shorter Magnetic Shielding (inclusion of magnetized hadron stopper)
  - New neutrino spectrometer layout
  - Conical vacuum vessel
  - Charm production including cascade production
  - Revised detector geometries and parameters

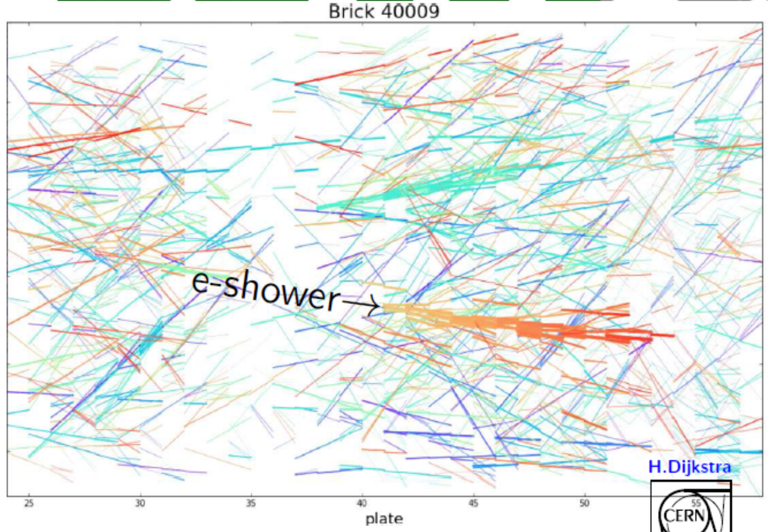
49 institutes
17 countries
~ 250 members

Courtesy: SHiP Collaboration

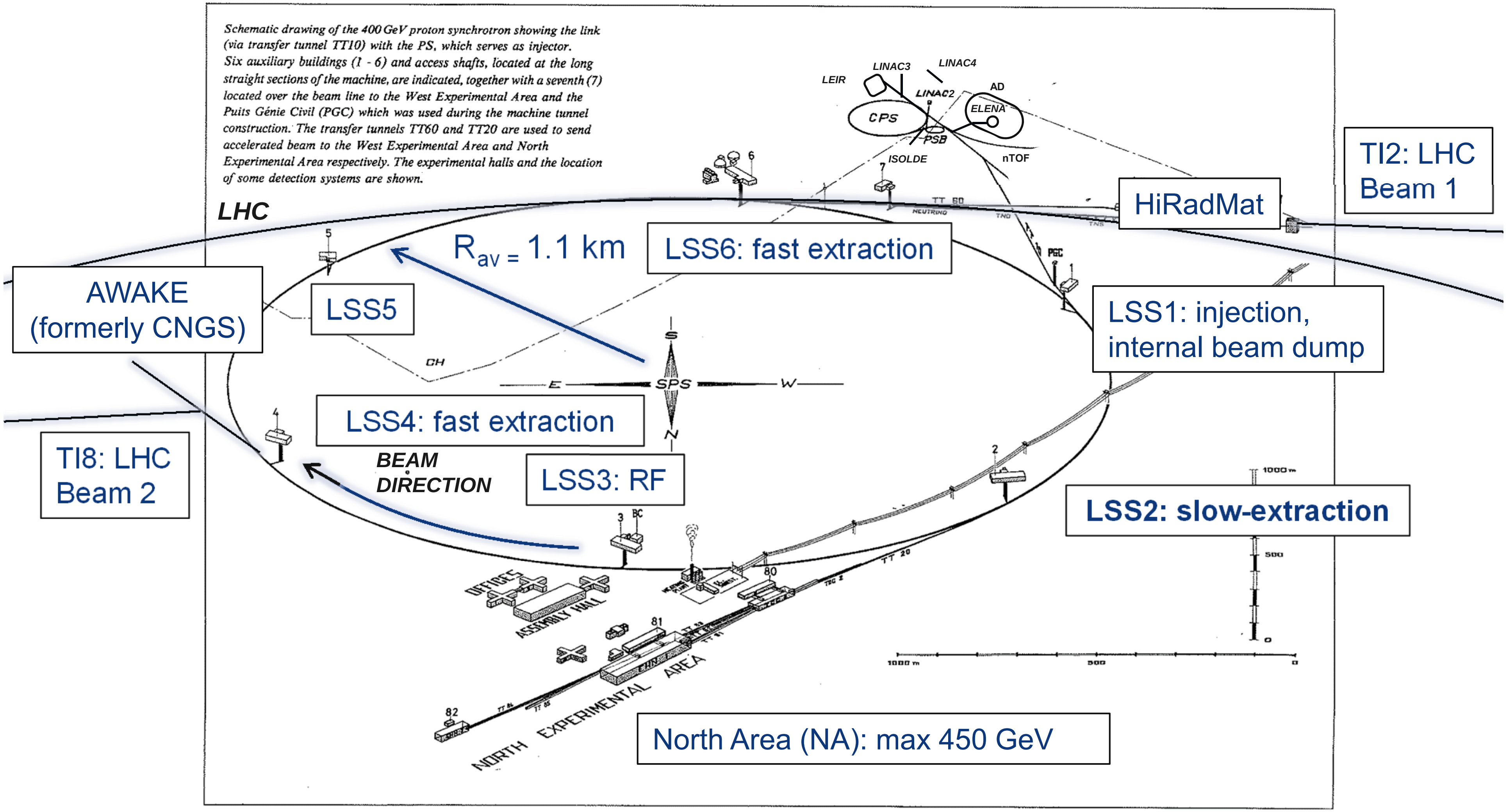
Neutrino physics / HS indirect detection

- Neutrino Physics:
  - ~40 m after target.
  - Pb/Emulsion "Target" similar to OPERA
  - Per SPS-spill(!) #CC interactions:
    - ν_μ + anti-ν_μ ~2
    - ν_e + anti-ν_e ~0.2
    - ν_τ + anti-ν_τ ~0.02
- Hidden particle scattering off electrons:
  - Machine learning technique to identify isolated e-shower
  - Use real OPERA emulsion-film data, mixed with MC e-showers → measure electron energy with 20-30%





CERN SPS today

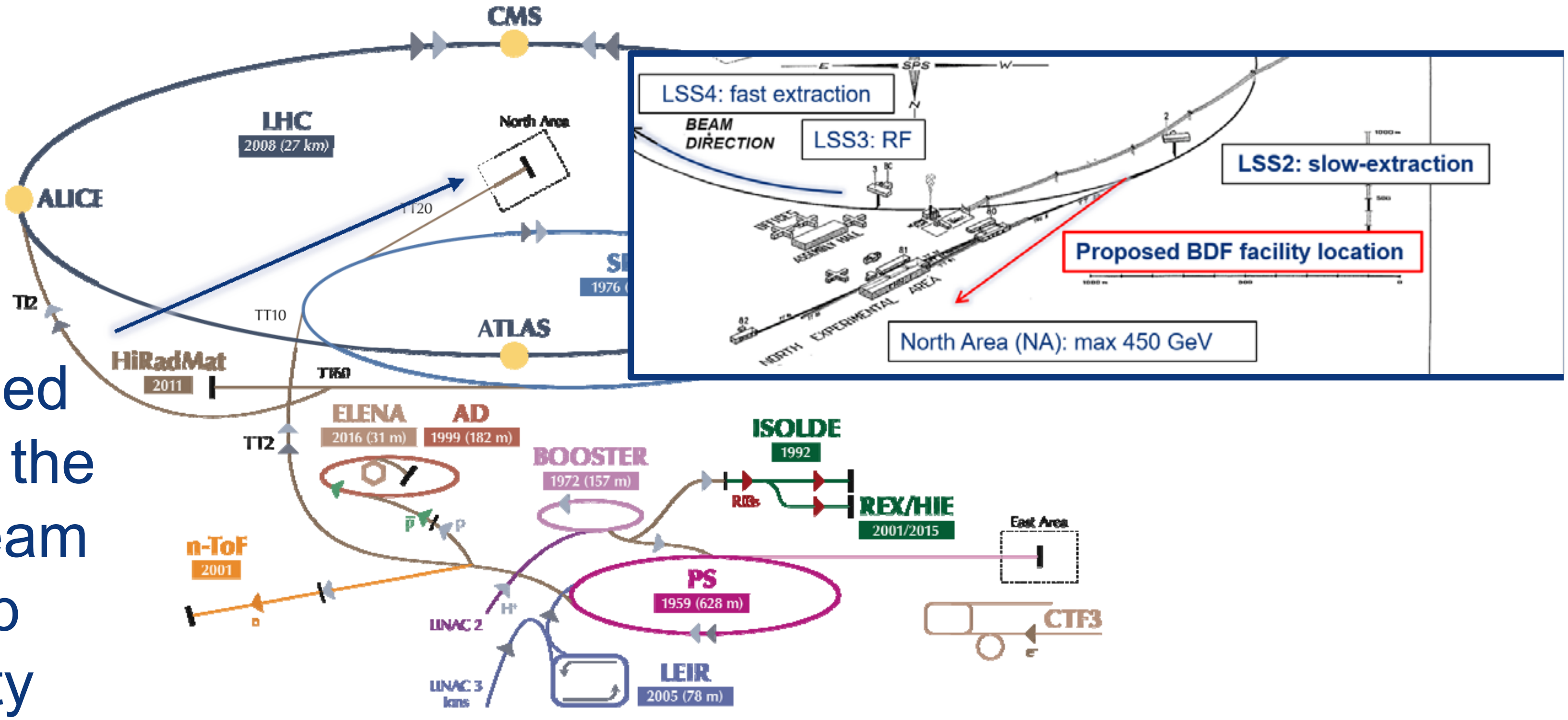


[1] J.B. Adams, The CERN 400 GeV Proton Synchrotron, 1977

Conception of the BDF facility

- Conceptual design of a general purpose fixed target facility for high intensity dump experiments in the SPS complex
- SHiP as the first possible experiment

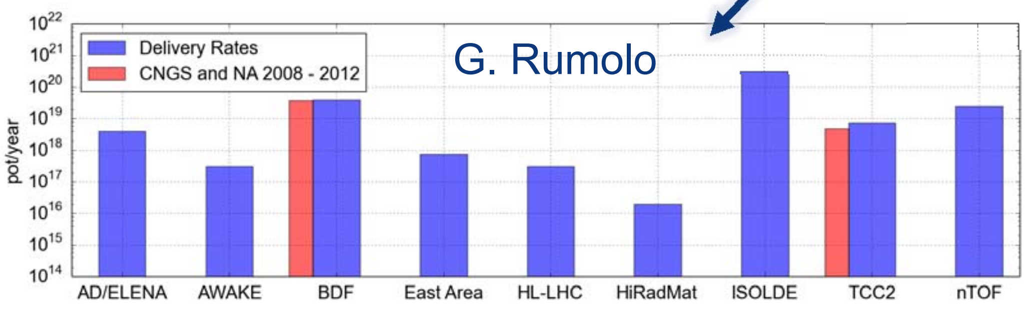
Proposed siting of the SPS Beam Dump Facility

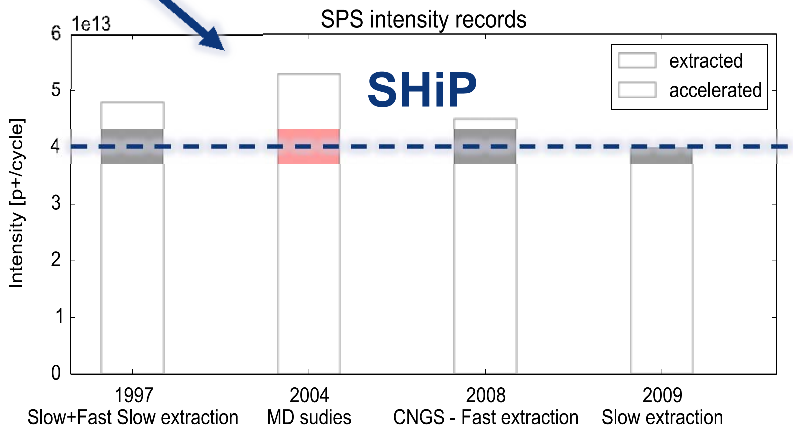


Requirements and parameters for SHiP

Parameter	SHiP	SPS Record	Comment
Extraction momentum [GeV/c]	400	450	RMS power limitation
Slow extracted int. [p$^+$]	**$4.2*10^{13}$**	4E13	2009 for FT program
Flat-top (~spill length) [s]	**1.2**	2.4 - 9.6	Request from experiment
Beam power on target [kW]	**355 (SX)**	480 (FX)	Average over super-cycle
Annual p$^+$ on target [POT]	$4*10^{19}$	$4.8*10^{19}$	CNGS maximum

M. Lamont





Slow extraction requirement → **Transfer line and radiation protection** ✗
Target engineering ✓

Civil engineering
Geotechnical and hydrogeology of site

Existing users

New beam line
Beam dilution

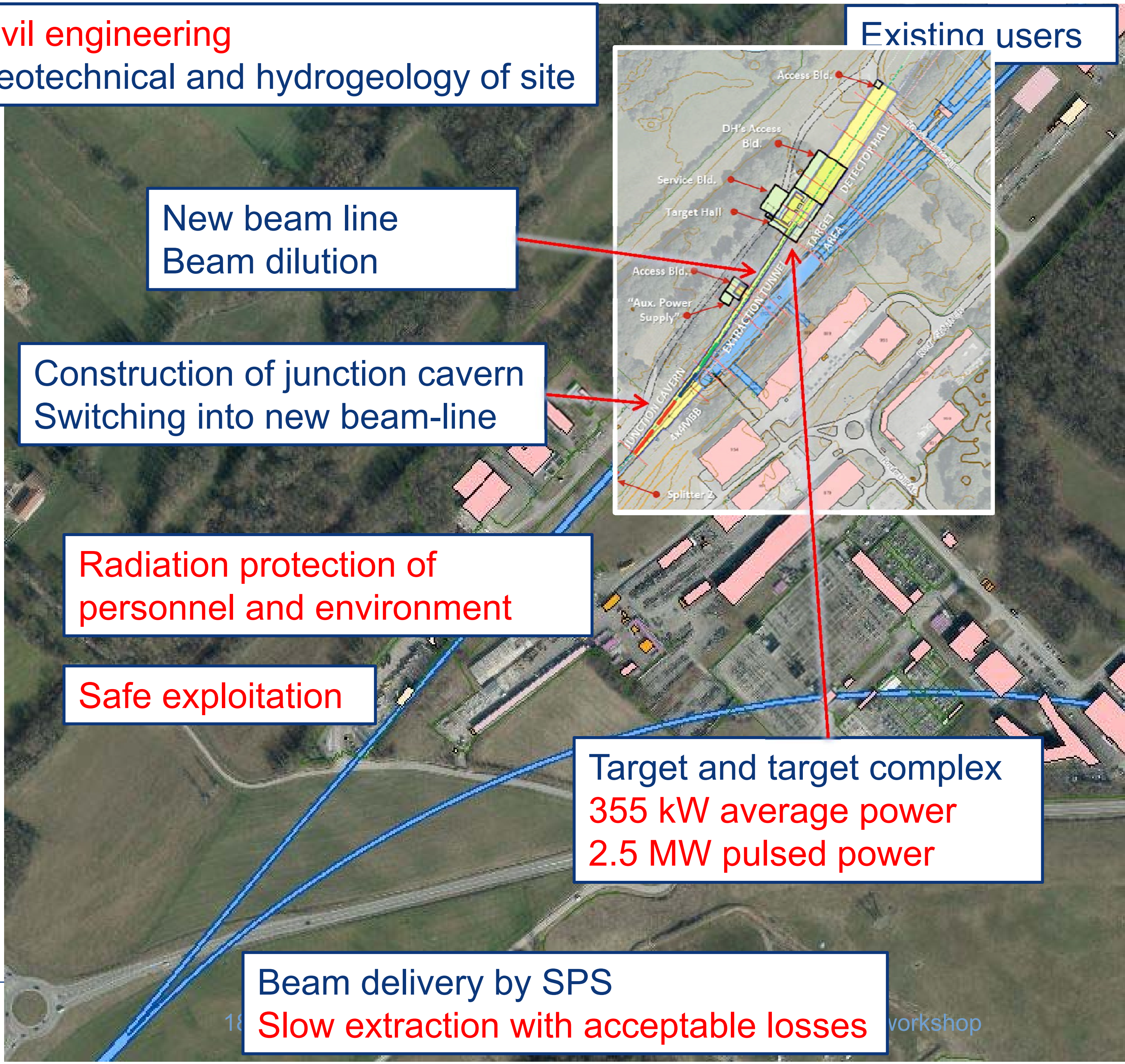
Construction of junction cavern
Switching into new beam-line

Radiation protection of
personnel and environment

Safe exploitation

Target and target complex
355 kW average power
2.5 MW pulsed power

Beam delivery by SPS
Slow extraction with acceptable losses

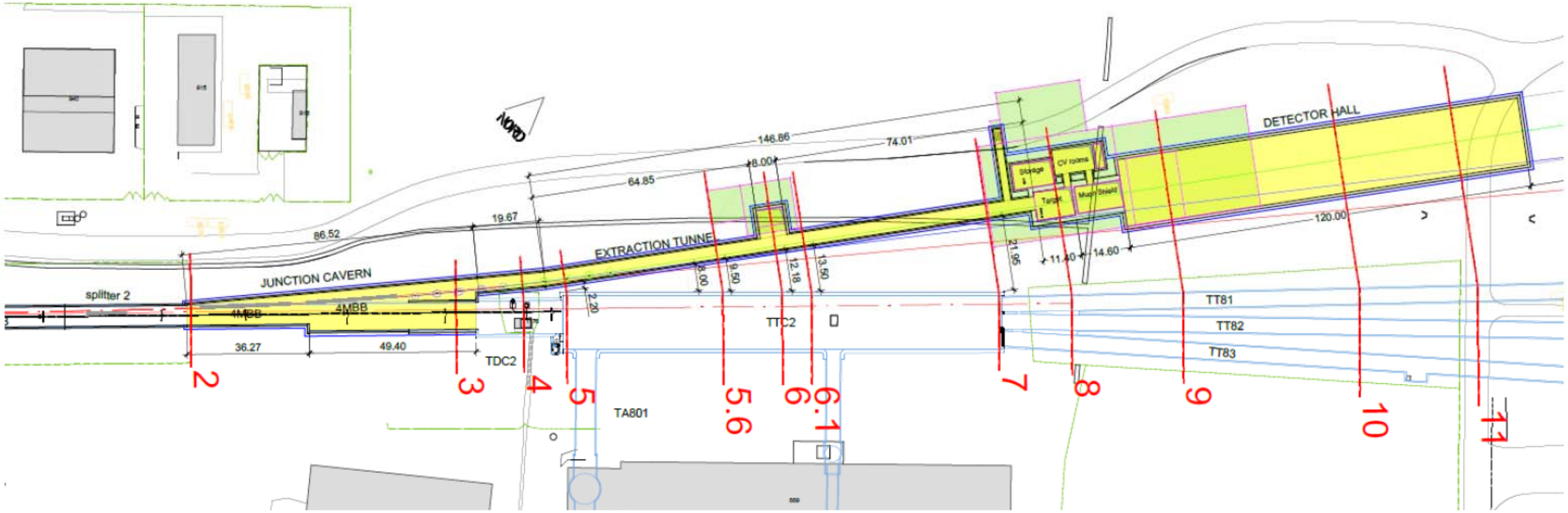


BDF Project study context

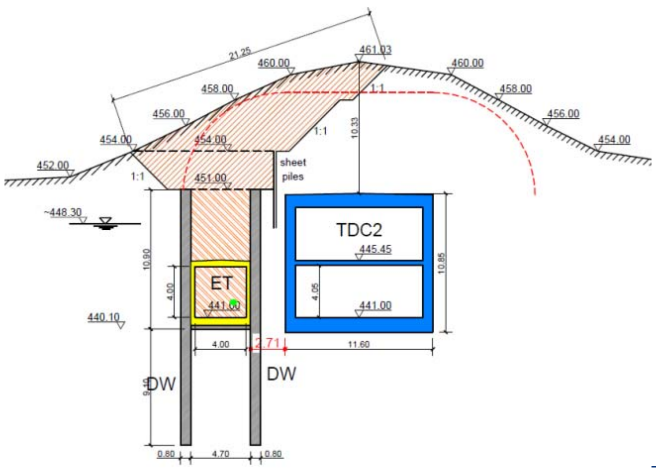
- Mandated to prepare a Comprehensive Design Report (CDR) of BDF by end of 2018 in view of the European Strategy for Particle Physics (~4 MCHF over 3 years)
- Decision on construction ~2021
- In the framework of the Physics Beyond Collider (PBC) study group
- Focus is to design facility for SHiP, but keep it open for future long-term users

BDF Project study deliverables

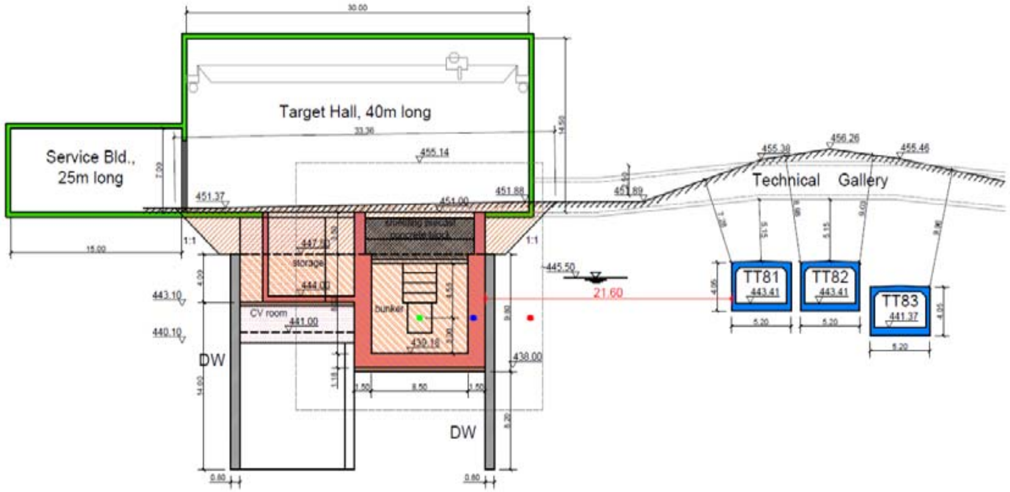
1. Beam requirements specification for all potential users
2. Evaluation of SPS performance reach per requested beam type
3. Design and feasibility evaluation for engineering subsystems (extraction, beam-lines, splitting, dilution, target and target complex, interface to experiment(s))
4. Preliminary integration and infrastructure study
5. Preliminary civil engineering design
6. RP simulation, impact and optimization studies
7. Safety impact studies
8. Preliminary project safety folder
9. Projection execution analysis and planning
10. Cost analysis



Top view of the new BDF underground and surface areas with the main cross sections along the beam-line



Cross section 4

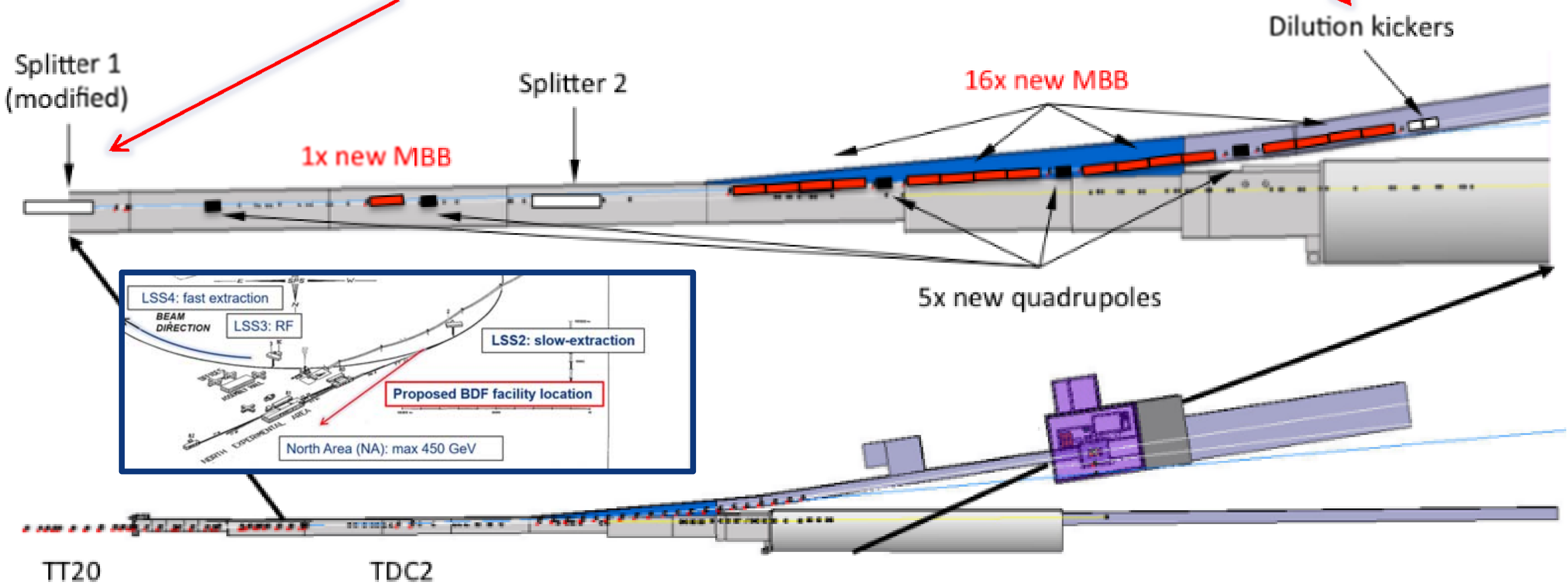


Cross section 8

BDF beam line

Beam to be painted on target during the spill to reduce stress on target

Splitter magnet need to be laminated: pulsing opposite field (deflection to left) and no splitting for BDF cycles



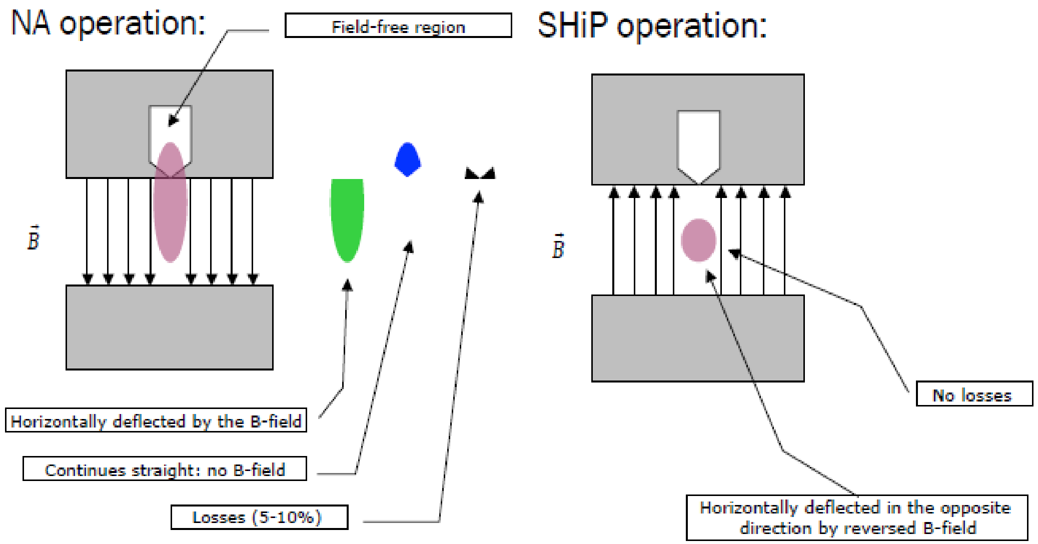
SPS

~ 200 m

North Area

Extraction line from SPS to target

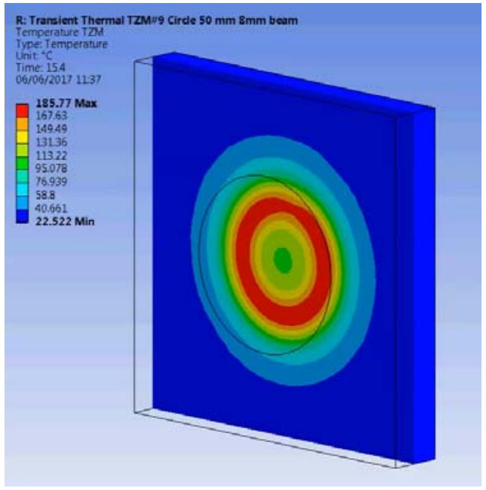
- Significant R&D for beam loss reduction in extraction from SPS (diffuser, low-Z septa wires, etc.)
- Replace existing splitter Lamberston magnet with bi-polar laminated version with larger aperture

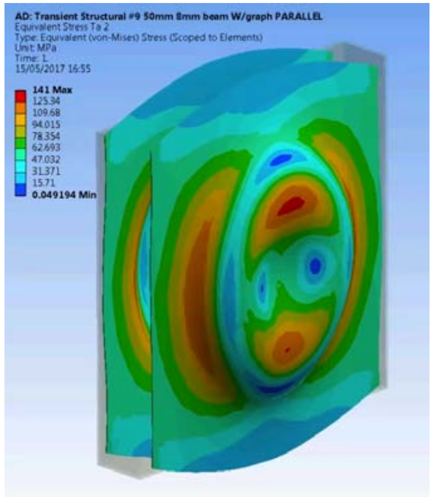


Beam dilution to target

- To avoid exceeding damage threshold of target a dilution system is required to sweep the beam over the spill
- Dilution system: 2 MPLS + 2 MPLV ~100 m upstream the target

Parameter	Value
Pattern	Circle
Sweep radius	50 mm
Number of turns per spill	4
Spill duration	1 s
Beam radius (1σ)	8 mm
Diluter rise time	62.5 ms

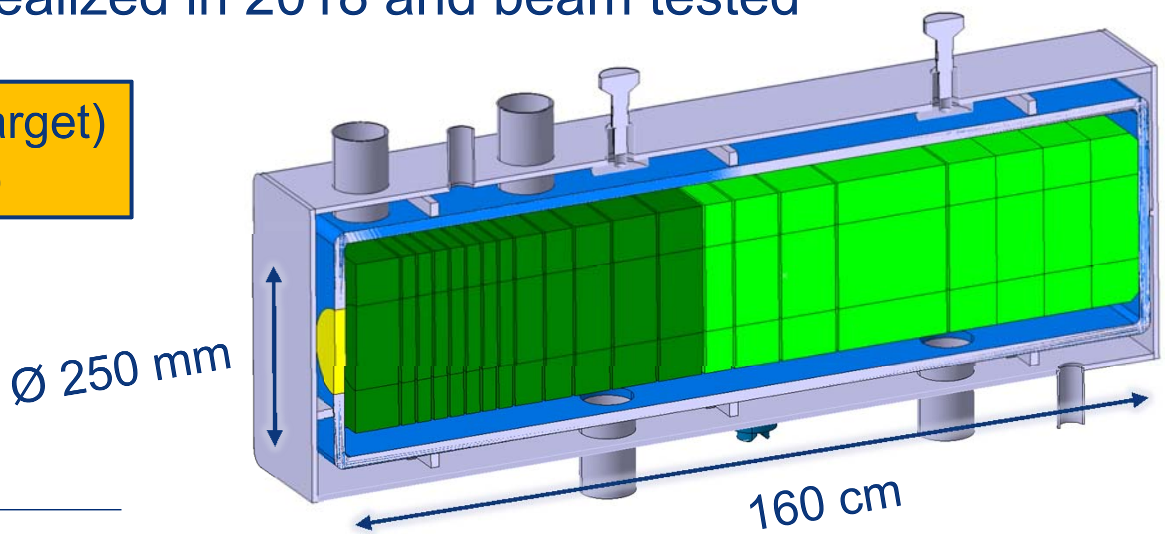




Target design requirements

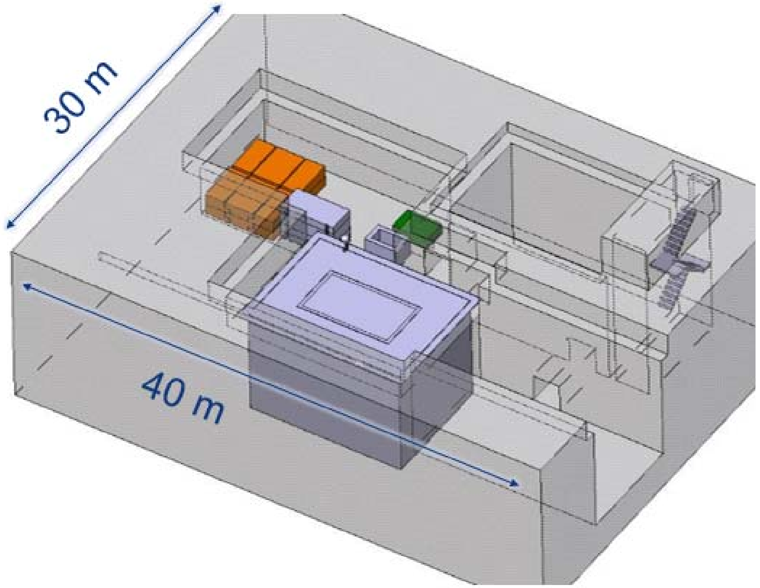
- Beam power 355 kW (**320 kW deposited**), 2.56 MJ/spill
- Target must be as dense as possible to maximize charm production and reduce neutrino backgrounds
- 150 cm long hybrid configuration / double containment
- Ta2.5W-cladded TZM (60 cm) + Ta-cladded W (80 cm)
- H_2O-cooled, 5 mm gap, ~4-5 m/s, 16-20 kW/m^2*K
- Prototype to be realized in 2018 and beam tested

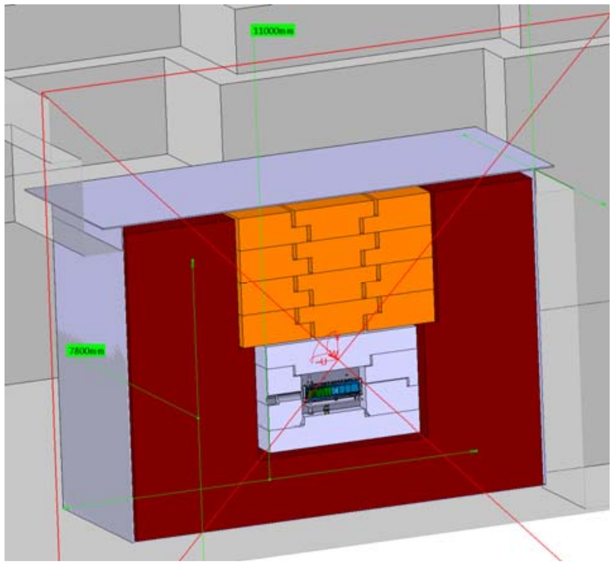
E. Lopez-Sola 20/09 (target)
M. Casolino 20/09 (RP)



Target complex design

- Target is located 15 m underground, relatively close to the CERN fence (~70 m)
- Cast-iron hadron absorber encloses production target (460 m^3) – part of it magnetized to sweep out $\mu^\pm$
- Target bunker inside an active circulation He-vessel
- Fully remote handling/manipulation as basis of design





M. Calviani 19/09
P. Avigni 19/09
M. Casolino 20/09

Radiation protection matters

- 355 kW → RP requirements dictates design of the facility
- High prompt & residual dose rates → shielding and remote interventions
- SPS slow extraction becomes crucial factor
- Target area and annex particularly critical
- Environmental impact

M. Casolino 20/09

Constraints have been highlighted and design optimized in the conceptual design of the facility (2015)

Ongoing BDF activities

- **Extraction and beam transfer**
  - Loss mitigation studies, novel solutions
  - Two polarity splitter magnet design and prototyping
  - TT20 optics studies
- **Target and target complex**
  - Beam dilution sweep on target optimization
  - Target material studies and characterization
  - Target cooling simulations
  - Target complex handling and integration studies
  - Target shielding studies
  - T6 target test preparation

- **Safety engineering**
  - Impact studies on existing installations and environment
  - Qualitative flooding risk assessment for the BDF target building
  - Definition of the strategy to perform the hydrogeological study
  - Preliminary list of hazards for the BDF & qualitative risk assessments
- **Radiation protection**
  - Update of the new, quite complex FLUKA geometry followed by update of estimates of prompt dose rates
  - Optimization of the design of the target bunker
  - The production of radionuclides in air, helium & water compartments/circuits of the BDF, beam extraction and transfer tunnels, TDC2/TCC2.
- **Integration**

Conclusions

- Preliminary conceptual design of a general purpose SPS Beam Dump Facility done during 2014-2015
- Entering Comprehensive Design Phase (2017-2019)
- Demonstrated it can be built with the requested performances, provided some key R&D are executed
- Realistic schedule has been drawn to start operation sometime after LS3 (~2026)
- R&D plan foreseen for 2017-2019 as input to the European Strategy for Particle Physics