NA: the future is colourful and dark

Mike Lamont

40 years SPS NA Physics Celebration

Acknowledgements: Gaia Lanfranchi, Lau Gatignon, Conventional Beams WG
QCD remains wonderfully intriguing

Action density:
4 dimensional structure of the long-distance aspects of the QCD vacuum

Derek B. Leinweber  http://www.physics.adelaide.edu.au
Higgs discovered with mass $\sim 125$ GeV.
No new particles found.
Direct detection – WIMP searches

It corresponds to a coupling \(-10^{-3}\) weaker than the weak coupling.
Strong motivation to extend the search

- **Sub-eV**: axions, axion-like particles
- **MeV – GeV**: RH neutrinos below the EW scale, axion-Like Particles, Light Dark Matter
- **>>TeV**: search for NP in clean and very rare flavour processes or in EDMs
Beam lines available/proposed in the North Area

M2: 100-160 GeV, mu beam
up to $10^{13} \mu/\text{year}$
→ $\text{NA64}^{++}$ (muons)

H4: 100 GeV e- beam
up to $5 \times 10^{12} \text{eot/ year}$
→ $\text{NA64}^{++}$ (electrons)

K12: 400 GeV p beam
up to $3 \times 10^{18} \text{pot/year (now)}$
→ $\text{NA62}^{++}$ (NA62-dump)
up to $10^{19} \text{pot/year (if upgraded)}$
→ $\text{KLEVER}$

BDF (proposed): 400 GeV p
up to $4 \times 10^{19} \text{pot/year}$
→ SHiP, TauFV

Highest energy proton, electrons and muon beams delivered for fixed target experiments in the world.
Conventional Beams at the North Area

Proposals followed by the CB WG - healthy mix of HS/QCD

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
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<tbody>
<tr>
<td>NA61++</td>
<td>Run NA61/SHINE at higher intensity and with better protection</td>
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<tr>
<td>NA64++ (e,h)</td>
<td>Increase electron flux and optimise hadron beams in the H4 line</td>
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<tr>
<td>NA64++ (u)</td>
<td>Study the possibility to install and run a NA64-like experiment with muons in EHN2</td>
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<tr>
<td>COMPASS++</td>
<td>Study new requests from COMPASS, including a RF separated beam</td>
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<tr>
<td>MUonE</td>
<td>Study the possibility to implement the MuonE experiment in the M2 beam for operation with ( \mu ) and e beams</td>
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<tr>
<td>NA62++</td>
<td>Optimise conditions for NA62 in beam dump mode for Hidden Sector searches</td>
</tr>
<tr>
<td>KLEVER</td>
<td>Study a new beam for a ( K_L \rightarrow \pi 0\nu\nu ) experiment at very high proton flux in ECN3</td>
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<tr>
<td>DIRAC++</td>
<td>Study implementation options for a DIRAC follow-up experiment at the SPS</td>
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<tr>
<td>NA60++</td>
<td>Study implementation options for a NA60 follow-up experiment with heavy ion beams</td>
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on behalf of the Conventional Beams working group
Report in support of ESPP update

Report from the Conventional Beams Working Group to the
Physics beyond Collider Study and to the European Strategy
for Particle Physics

D. Banerjee, J. Bernhard, M. Brugger, N. Charitonidis, G. L. d’Alessandro, N. Doble, M. van Dijk,
L. Gatignon, A. Gerbershagen, E. Montbarbon, M. Rosenthal
on behalf of the Conventional Beams working group

Contact person: Lau Gatignon, email Lau.Gatignon@cern.ch
NA62++: dump mode

Transfer full proton intensity on TAX with T10 out and reduce flux of upstream pion and kaons decaying to muons. Muons need to be efficiently swept as zero background from SM required. Successful benchmarking of simulation with experimental data performed.

Configuration with closed TAXes and modified 1st achromat for optimum muon sweeping.
NA64++: electrons, muons and hadrons

NA64++ (electrons): extension beyond 2021 to accumulate up to $5 \times 10^{12}$ eot in H4

NA64++ (muons): use the 100-160 GeV muon beam in COMPASS area to study hidden sector with muon couplings. Preliminary test done in 2017 with the COMPASS setup show that the purity of the muon can be kept under control. Interplay between NA64, COMPASS and MUonE under study.

NA64++ ($K_{L,S}, \pi^0, \eta, \eta' \rightarrow \text{invisible}$): produced via charge exchange reactions $\pi(K) p \rightarrow M^0 n + E_{\text{miss}}$

NA64-mu - Phase 1:
- Upstream location identified in PPE211, compatible with current downstream COMPASS installations.
- Calculated optics that fulfil well user requirements.
- Study for optimisation of beam momentum measurement completed.
- Preliminary cost estimate ready for possible installation in $\geq 2021$.

Phase 2: Optics ready, integration study continues…

Dipanwita Banerjee
Johannes Bernhard
Modification and optimization of the proton beam transport in P42 to the T10 target. Intense target production studies:

- Production angle on T10 target increased from 2.4 to 8 mrad. \( \Lambda \) production suppressed. Loss in \( K_L \) production compensated.

- Reduce photon background by pair conversion in photon converter, material and thickness study in FLUKA.

- Optimize configuration of 3 groups of bending magnets for reduction of muon background with full FLUKA model including magnetic fields etc...

7 times higher than NA62: upgrades to target area and transfer lines (RP, target, TAXes...) required

For 60 SM events, need:

- \( 5 \times 10^{19} \) pot
  - e.g. \( 2 \times 10^{13} \) ppp/16.8 s \( \times \) 5 yrs
Aerial picture of the North Area

NA62++ @ K12
KLEVER

NA64++ (μ) @ M2

NA64++ (e) @ H4

SHiP, tauFV @ BDF

The hidden sector “campus”
Beam Dump Facilities

- BDFs ideal for exploring light super-weakly interacting particles and Light Dark Matter
  - **Luminosity** (yield of $\pi$, K, D, B decay and photons):
    - HL-LHC: $\sim 10^{35} \text{ cm}^{-2}\text{s}^{-1} \times 10^7 \text{ s} = 10^{42} \text{ cm}^{-2}$
    - SPS (1 m long high A/Z target): $4 \times 10^{13} \times 6 \times 10^{24} \text{ cm}^{-3} \times 10^2 \text{ cm} \times 10^6 \sim 2 \times 10^{46} \text{ cm}^{-2}$
    - Superior luminosity compensates for lower energy (e.g. yield of charm hadrons $\sim 10^{16}$@HL-LHC vs $\sim 10^{18}$@SPS)
  - Geometrical acceptance
  - Long lifetimes
  - Background suppression
Beam delivery by SPS
Slow extraction with acceptable losses

Civil engineering
Geotechnical and hydrogeology of site

Radiation protection of personnel and environment

New beam line
Beam dilution

Re-construction of junction cavern
Switching into new beam-line

Existing users

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

North Area
Prevesen campus
Target Complex & Experiment Hall

Beam line, target access and service building

Target complex

Target bunker

Experiment service building

Experiment surface hall

Experiment underground hall

Shielding mounds

BDF Comprehensive Design Study in pre-publication

Pablo Santos Diaz
**SHiP**

**Physics case** based on $2 \times 10^{20}$ protons on target (5 years of nominal operation)
Signal yields from $>10^{18}$ D mesons, $>10^{16}$ tau, $>10^{21}$ photons ($>100$ MeV)

**Dual detector system:**
1. Search for HS decays ("HS detector")
2. Neutrino physics and search for LDM recoil signatures ("SND")

4e13 PoT/ 1 s spill
**TauFV**

Search for Lepton Flavour Violation and rare decays

Using a thin in-line target to intercept about 2% of the intensity delivered to the SHiP target, would have access to close to $8 \times 10^{13}$ tau lepton and $5 \times 10^{15} D_0$ meson decays.
Beam loss from slow extraction is *unavoidable* and has to be *controlled and optimized*:

- *Induced activation in Long Straight Section 2 (LSS2) increases in direct proportion to the beam loss on the septum*
SHiP request for POTs demands a factor of x 4 - 5 loss reduction to keep future activation levels in LSS2 comparable to today:

- 4E19 POT for SPS BDF and ~ 1E19 POT for North Area parallel operation

* Measured ~30h after shutdown at ~1 m from beam line, peak at ZS plotted.
Major effort to reduce losses

- Implementation of dynamic optics control (COSE) to hold separatrix stationary during spill
  - Thin bent crystal installed upstream ZS
    - Crystal channeling creates depleted density region at ZS wires
- Apply higher-order multipole fields during extraction:
  - Reduce density of beam impinging the ZS wires: 35 – 45%
  - At the expense of increasing extracted beam emittance

Driven and supported by the members of SPS-CASE WG and SLAWG

Fruitful collaboration between a large number of groups and experimental collaborations!
Dedicated R&D effort including 2 PhD thesis topics

Brennan Goddard, Matthew Fraser et al
Combining techniques

Crystal inserted and aligned with octupoles during afternoon of 1st November 2018:

Preliminary result:
Angular scan 1
Angular scan 2

Losses at ZS
\[ \sim 0.55 \times 0.6 = 0.33 \]

In 2018, different loss reduction concepts were validated in MD tests:

- Included passive and active diffusers (crystal shadowing of ZS) and phase space folding
- Factor of \( \sim 3 - 4 \) loss reduction at ZS demonstrated
- Scope for further loss reduction improvement

The magic factor of 4 - 5 reduction to accommodate SHiP/BDF does appear to be in reach!
3. The North Area Beam Transfer Lines

The beam lines to the North Area have been designed for 400 GeV/c. The geometry is shown in Figure 3.

Fig. 3 Geometry of the proton beam lines to the North Area
THE STEEL SEPTUM MAGNETS FOR BEAM SPLITTING AT THE CERN SPS

by

L. Evans, A. Ijspeert, B. de Raad, W. Thomi, E. Weisse

CERN-SPS/ABT/77-13

New laminated bipolar splitter/switch
with reduced saturation

Jakub Kurdej
Some loving care and attention required!
NA: the future is colourful and dark and interesting!

Physics motivation remains strong
  The North Area is an ideal place to search for Hidden Sector at
  with NA62, NA64, SHiP etc. in $< O(10)$ GeV range
  Unique QCD possibilities

SPS is adapting well to the foreseen challenges

NA remains vitally important as a test facility