Forward Search Experiment at the LHC

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Seminar at the University of Geneva
27/2/2019

FASER website:
https://twiki.cern.ch/twiki/bin/view/FASER/WebHome
FASER: THE IDEA

• New physics searches at the LHC focus on high $p_T$. This is appropriate for heavy, strongly interacting particles
  - $\sigma \sim \text{fb to pb} \Rightarrow \text{In Run-3 } N \sim 10^2 - 10^5$, produced $\sim$ isotropically

• However, if new particles are light and weakly interacting, this may be completely misguided. Instead can exploit
  - $\sigma_{\text{inel}} \sim 100 \text{ mb} \Rightarrow \text{In Run-3 } N \sim 10^{16}$, $\theta \sim \Lambda_{\text{QCD}} / E \sim 250 \text{ MeV} / \text{TeV} \sim \text{mrad}$

• FASER is a proposed experiment designed to cover this scenario at the LHC
  • Detector to be placed 480m from IP1 directly on the beam collision axis line of sight (LOS) with transverse radius of only 10cm covering the mrad regime
FASER LOCATION

- FASER will be situated along the beam *collision* axis line of sight (LOS)
  - ~480 m from IP
  - after beams start to bend
  - a few meters from the LHC beamline

TI12 unused tunnel, that intersects LOS 480m from IP1
FASER would be situated at the bottom of the TI12 tunnel close to the LHC. TI12 was the old injection line for LEP, and is now unused. TI12 slopes upwards, and the LOS emerges from the tunnel floor. In order to install the FASER detector on the LOS a small amount of civil engineering work needs to be done, to lower the floor of the tunnel (50cm maximum). After such digging a 5m long detector can be situated along the LOS.
EXAMPLE PHYSICS CASE (DARK PHOTONS)
• Dark matter is our most solid evidence for new particles. In recent years, the idea of dark matter has been generalized to dark sectors

• Dark sectors motivate light, weakly coupled particles (WIMPless miracle, SIMP miracle, small-scale structure, ..)

• A prominent example: vector portal, leading to dark photons

• The resulting theory contains a new gauge boson $A'$ with mass $m_{A'}$ and $\varepsilon Q_f$ couplings to SM fermions $f$
DARK PHOTON PROPERTIES

• Produced in meson decays, e.g.,

\[ B(\pi^0 \rightarrow A'\gamma) = 2\epsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 B(\pi^0 \rightarrow \gamma\gamma), \]

and also through other processes

• Travels long distances through matter without interacting, decays to e^+e^-, \mu^+\mu^- for \( m_{A'} > 2 \, m_\mu \), other charged pairs

\[ \bar{d} = c \frac{1}{\Gamma_{A'}} \gamma_{A'} \beta_{A'} \approx (80 \, \text{m}) \, B_e \left(\frac{10^{-5}}{\epsilon}\right)^2 \left[\frac{E_{A'}}{\text{TeV}}\right] \quad E_{A'} \gg m_{A'} \gg m_e \]

• TeV energies at the LHC \( \rightarrow \) huge boost, decay lengths of \( \sim 100 \, \text{m} \) are possible for viable and interesting parameters
FASER takes advantage of the huge number of light mesons ($\pi^0, \eta, \ldots$) that are produced at the LHC, predominantly in the very forward direction. For example for $E(\pi^0) \geq 10$ GeV,

- 2% of $\pi^0$s fall in FASER acceptance;
- whereas the FASER acceptance covers just $(2 \times 10^{-6})$% of the solid angle.

Run-3 (0.15/ab) will produce a huge number of $\pi^0$s in FASER angular acceptance. Even with large suppression ($\varepsilon^2 \sim 10^{-8} - 10^{-10}$ for relevant region of phase space) can still have very large number of dark photons produced.

LHC can be a dark photon factory!
DARK PHOTONS IN FASER

- Simulations greatly refined by LHC data
- Production is peaked at $p_T \sim \Lambda_{QCD} \sim 250$ MeV
- Enormous event rates: $N_\pi \sim 10^{15}$ per bin

- Production is peaked at $\rho_A \sim \Lambda_{QCD} \sim 250$ MeV
- Rates highly suppressed by $\varepsilon^2 \sim 10^{-10}$
- But still $N_A' \sim 10^5$ per bin

- Only highly boosted $\sim$TeV A's decay in FASER
- Rates again suppressed by decay requirement
- But still $N_A' \sim 100$ signal events, and almost all are within 20 cm of “on axis”

note this is an old slide, and FASER volume $R=10$cm now!
ALP production using the LHC as a beam-dump experiment. Very high energy photons produced in LHC collisions, interacting with material in the TAN can produce ALPs. The ALPs (with ~TeV energy) then propagate in a straight line, and can decay inside FASER (480-140 = 340m from their production point).
ALP production using the LHC as a beam-dump experiment. Very high energy photons produced in LHC collisions, interacting with material in the TAN can produce ALPs. The ALPs (with ~TeV energy) then propagate in a straight line, and can decay inside FASER (480-140 = 340m from their production point).

Assuming angular coverage of TAN is <1mrad

note this old plots, and FASER volume R=10cm and decay length 1.5m now!
THE TI12 ENVIRONMENT
BEAM BACKGROUNDS

- FLUKA simulations and \textit{in situ} measurements have been used to assess the backgrounds expected in FASER.
- FLUKA simulations studied particles entering FASER from:
  - IP1 collisions (shielded by 100m of rock)
  - off-orbit protons hitting beam pipe aperture in dispersion suppressor (close to FASER) (following diffractive interactions in IP1)
  - beam-gas interactions
- Expect a flux of high energy muons ($E>10$ GeV) of $0.4\text{cm}^{-2}\text{s}^{-1}$ at FASER for $2\times10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosity from IP1 collisions.

![Fluence rate (GeV$^{-1}$ cm$^{-2}$ s$^{-1}$) for muons: 10 GeV threshold](image1)

![Fluence rate spectra at FASER (above 10 GeV) for the LHC](image2)

Large muon charge asymmetry at FASER due to LHC bending magnets

Huge flux of high energy neutrinos
Due to bending from LHC magnets, muon flux on LOS is reduced: $\mu^-$ tend to be bent to the left, $\mu^+$ to the right of FASER.

<table>
<thead>
<tr>
<th>Energy threshold [GeV]</th>
<th>Charged particle flux [cm$^{-2}$ s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.40</td>
</tr>
<tr>
<td>100</td>
<td>0.20</td>
</tr>
<tr>
<td>1000</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Expected charged particle rate for different energy thresholds ($2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$)
• Measurements using emulsion detectors installed in TI12 in 2018 running confirm expected particle flux
• Measurements using TimePix BLM in TI12 confirm that particle flux is correlated with luminosity in IP1

BEAM BACKGROUND

10^5
10^4
10^3
10^2
10
1
1
0
-0.5
-1
1
0.5
MeV
GeV

w/o tungsten (E>50MeV)
with tungsten (E>1GeV)

particles from IP1

particles from LHC beam line

Measured angle in emulsion detector

Line of sight

x

y

z
TI12 RADIATION LEVEL

• Radiation level predicted to be very low in TI12 due to dispersion function of LHC at this location
  – Radiation comes from off-momentum protons (following diffractive processes in IP1) hitting beam aperture, and causing showers
  – Dispersion function defines where this happens – FASER location one of the quietest!

• Measurements by BatMon radiation monitor in 2018 running confirm FLUKA expectations of:
  – less than $5 \times 10^{-3}$ Gy/year
  – less than $5 \times 10^{-7} \, 1\, \text{MeV} \, \text{neutron equivalent fluence} / \, \text{year}

• FASER detector does not need radiation hard electronics
The detector consists of:
- Scintillator veto
- 1.5m long decay volume
- 2m long spectrometer
- EM calorimeter
THE FASER DETECTOR

The detector consists of:
- Scintillator veto
- 1.5m long decay volume
- 2m long spectrometer
- EM calorimeter

Signal signature

1. No signal in the veto scintillator;
2. Two high energy oppositely charged tracks, consistent with originating from a common vertex in the decay volume, and with a combined momentum pointing back to the IP;
3. For A'\textrightarrow ee decay: Large EM energy in calorimeter. EM showers too close to be resolved.

Magnets needed to separate the A' decay products sufficiently to be able to be resolved in tracker
For detector to be situated on LOS, require small amount of digging in TI12 tunnel.
Maximum digging depth ~50cm - to avoid drainage membrane.
Detailed study by CERN civil engineering department.
With this design can fit ~5m long detector centered on LOS.
The FASER magnets are 0.6T permanent dipole magnets based on the Halbach array design:
- Thin enough to allow the LOS to pass through the magnet center with minimum digging to the floor in TI12
- Minimized needed services (power, cooling etc..)

To be constructed by the CERN magnet group:
- Cost 450kCHF
The FASER Tracker will be made up of 3 tracking stations
Each containing 3 layers of double sided silicon micro-strip detectors
  • Spare ATLAS SCT modules will be used
    • 80µm strip pitch, 40mrad stereo angle
    • Many thanks to the ATLAS SCT collaboration!
  • 8 SCT modules give a 24cm x 24cm tracking layer
  • 9 layers (3/station, 3 stations) => 72 SCT modules needed for the full tracker
    • $10^5$ channels in total

Due to the low radiation in TI12 the silicon can be operated at room temperature, but the detector needs to be cooled to remove heat from the on-detector ASICs

Tracker readout using FPGA based board from University of Geneva (already used in Baby MIND neutrino experiment)
University of Geneva (DPNC) taking large responsibility in the FASER Tracker:
- Tracking mechanics, being designed and built by DPNC mechanics team
- Tracker readout design and FW by the DPNC electronics team, using existing GPIO board

1 GPIO board per tracking layer (9 in total)

SCT module QA currently ongoing at CERN to identify 80 good spare modules – this is using non-final readout
TRACKER COOLING

- Due to the low radiation in TI12 the silicon can be operated at room temperature, but the detector needs to be cooled to remove heat from the on-detector ASICs.
- Design of tracking layer ongoing to give sufficient thermal and mechanical properties, whilst minimizing material in tracking volume.
- Plan to use simple water chiller with inlet temperature <10degrees.

Example FEA analysis in tracer design:

Dry air to be provided by CERN CV group. Will need DCS and interlock to turn off tracker if cooling or humidity control fails.
• FASER EM calorimeter for:
  • Measuring the EM energy in the event
  • Electron/photon identification
  • Triggering
• Will use 4 spare LHCb outer ECAL modules
  • Many thanks to LHCb for allowing us to use these!
  • 66 layers of lead/scintillator, light out by wavelength shifting fibers
    • 25 radiation lengths long
  • Readout by PMT (no longitudinal shower information)
  • dimensions: 12cmx12cm – 75cm long (including PMT)
  • Provides ~1% energy resolution for 1 TeV electrons
    • Resolution will degrade at higher energy due to not containing full shower in calorimeter
SCINTILLATORS

- Scintillators used for vetoing charged particles entering the decay volume, and for triggering
  - To be produced at CERN scintillator lab
  - PMT readout
  - Require extremely efficient charged particle veto (eff > 99.99%)
    - Achievable with the current design
Trigger rate expected to be ~600 Hz dominated by muons from IP.
Trigger will be an OR of triggers from scintillators and from the ECAL.
No signals shared with ATLAS, need LHC orbit and clock signals, and for offline analysis ATLAS luminosity.
Readout and trigger logic needs to be in TI12 tunnel, as not sufficient time to send signals to surface and back. Event builder on surface (in SR1)
DPNC making large contributions to the TDAQ. Trigger Logic Board is same GPIO board used for tracker readout, with dedicated firmware to be written by DPNC electronics team.
PHYSICS PERFORMANCE
EXPECTED PERFORMANCE – Track signature

- Main backgrounds radiative processes associated with high energy muons entering the detector from the IP
  - All can be vetoed by scintillator at front of detector
  - Potential small backgrounds from neutrino interactions inside the detector
    - Very low rate, and give different detector signature allowing to reject events
- Efficiency for separating very closely spaced tracks important for very high energy signals

**Horizontal Track Separation**

<table>
<thead>
<tr>
<th>Energy (TeV)</th>
<th>Station 1</th>
<th>Station 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td>2</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td>5</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
</tbody>
</table>

**Signal Efficiency**

- loose selection

Efficiency that signal tracks are separated by >0.3mm in 2nd / 3rd tracking stations

Truth level studies
EXPECTED PERFORMANCE – Track signature

- Main backgrounds radiative processes associated with high energy muons entering the detector from the IP
  
  - All can be vetoed by scintillator at front of detector
  
  - Potential small backgrounds from neutrino interactions inside the detector
    
    - Very low rate, and give different detector signature allowing to reject events
  
  - Efficiency for separating very closely spaced tracks important for very high energy signals

GEANT4 studies
G4 simulation of a signal dark photon decay to $e^+e^-$
Simulation in development
EXPECTED SENSITIVITY

- Sensitivity for dark photons
  - Assuming no background and 100% signal efficiency
  - Curves only slightly effected by O(1) changes in efficiency

Even with 10/fb (to be collected by end of 2021?) have sensitivity to uncharted territory.
With full Run 3 dataset (150/fb) significant discovery potential.
EFFECT OF SELECTION EFFICIENCY

- To take into account an inefficiency due to the analysis selections
  - Defined loose selection: signal tracks separated by >0.3mm in 2\(^{nd}\) and 3\(^{rd}\) tracking stations
  - Defined tight selection: signal tracks separated by >0.3mm in all tracking stations
- Sensitivity basically unchanged for loose selection
- Tight selection loose some sensitivity
EXPECTED PERFORMANCE – 2 photon signature

- For ALP→γγ decay, magnetic field does not help separate closely spaced decay products
- We investigated calorimeter / pre-shower to allow to be able to resolve closely spaced (~1mm) high energy photons (>500 GeV) - seems very challenging

![Horizontal Photon Separation](chart.png)
EXPECTED PERFORMANCE – 2 photon signature

• For ALP\textrightarrow\gamma\gamma decay, magnetic field does not help separate closely spaced decay products

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Preliminary studies suggest that events with no tracks and a large amount of EM energy in the calorimeter would be \textsim background free \textrightarrow an ALP signal would be detectable without the need to resolve the 2 photons.

Further studies show an interesting background would be high energy neutrino’s interacting in the calorimeter to give large EM showers

  - either muon neutrinos leading to hadronic showers with \pi0,
  - or (more rarely) electron neutrinos interacting to give electrons

First time I have heard of neutrino interactions in the detector being a background for a collider search!

We are considering to have a scintillator pre-shower to give a small amount of longitudinal information which could be used to veto such neutrino interaction events.
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In longer term investigating installing a fine granularity silicon pre-shower to be able to separate close-by photons. Under investigation at University of Geneva.
AXION LIKE PARTICLES (ALPs)

- Assuming background free single-photon like search for ALPs sensitivity for 10/fb and 150/fb.
POSSIBLE NEUTRINO MEASUREMENTS

Huge flux of neutrinos through FASER could allow for interesting neutrino measurements e.g. $\nu_\mu$ CC cross section in unexplored region $E>400$ GeV.
There could also be interesting possibilities for $\nu_\tau$ measurements at the FASER location (e.g. using emulsion detectors)
POSSIBLE FUTURE UPGRADE - FASER 2

- A potential upgraded detector for HL-LHC running, would increase sensitivity further
- Increasing detector radius to 1m would allow sensitivity to new physics produced in heavy meson (B, D) decays increasing the physics case beyond just the increased luminosity

FASER 2 therefore becomes very strong compared to low energy experiments for certain models (dark Higgs), due to large B/D production rates at LHC: \( \frac{N_B}{N_\pi} \sim 10^{-2} \) (~10^{-7} at beam dump expts)
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Design of FASER 2 experiment unclear. Difficult to build a magnet of sufficient size!
**PBC BENCHMARK SUMMARY**

- FASER has a full physics program: can discover all candidates with renormalizable couplings (dark photon, dark Higgs, HNL); ALPs with all types of couplings ($\gamma$, $f$, $g$); and examples that are not PBC benchmarks.

<table>
<thead>
<tr>
<th>Benchmark Model</th>
<th>FASER 1</th>
<th>FASER 2</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC1: Dark Photon</td>
<td>✓</td>
<td>✓</td>
<td>Feng, Galon, Kling, Trojanowski, 1708.09389</td>
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<tr>
<td>BC1': U(1)$_{B-L}$ Gauge Boson</td>
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<td>✓</td>
<td>Bauer, Foldenauer, Jaeckel, 1803.05466; 1811.12522</td>
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<tr>
<td>BC2: Invisible Dark Photon</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>BC3: Milli-Charged Particle</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>BC4: Dark Higgs Boson</td>
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<td>Feng, Galon, Kling, Trojanowski, 1710.09387 Batell, Freitas, Ismail, McKeen, 1712.10022</td>
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<td>BC5: Dark Higgs with hSS</td>
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<td>BC6: HNL with $e$</td>
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<td>Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212</td>
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<td>BC7: HNL with $\mu$</td>
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<td>BC8: HNL with $\tau$</td>
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<td>Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212</td>
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<td>BC9: ALP with photon</td>
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<td>Feng, Galon, Kling, Trojanowski, 1806.02348</td>
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<td>BC10: ALP with fermion</td>
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<tr>
<td>BC11: ALP with gluon</td>
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</table>
CURRENT STATUS

- FASER Letter of Intent submitted to the LHCC in July
  - arXiv:1811.10243
- Technical Proposal submitted to LHCC in November
  - arXiv:1812.09139
- LHCC recommended experiment to be approved
- CERN Research Board positive about FASER, but postponed approval to March to allow FASER LS2 work to be integrated into LS2 schedule
- Detector designed to be affordable and fast to construct and install
  - Utilizing spare modules from existing experiments
  - Minimizing services needed where possible
  - Total detector cost <1MCHF (including contingency)
  - Cost to be borne by CERN (civil engineering, transport, services)
- Funding for detector construction/operation secured from Simons Foundation and Heising-Simons Foundation, contingent on CERN approval
  - Installation in LS2, data-taking in Run 3
SUMMARY AND OUTLOOK

• FASER is a proposed small, fast and cheap experiment to be installed in the LHC during LS2, to take data in Run 3
  • Taking advantage of already existing tunnel infrastructure and using spare detector parts from existing experiments

• It targets light, weakly-coupled new particles at low $p_T$, runs simultaneously with, and is complementary to, ATLAS/CMS, allowing to fill a possible hole in the current LHC new physics search programme
  • FASER has significant discovery potential for dark photons and other light, weakly coupled, new physics particles

• A possible upgrade FASER 2, with a bigger detector (radius = 1m) in LS3 would allow sensitivity to additional scenarios, including new particles produced in heavy meson decays

• The University of Geneva is making critical contributions to FASER!
THE FASER COLLABORATION

Akitaki Ariga,1 Tomoko Ariga,1,2 Jamie Boyd,3 Franck Cadoux,4 David W. Casper,5 Yannick Favre,4 Jonathan L. Feng,5 Didier Ferrere,4 Iftah Galon,6 Sergio Gonzalez-Sevilla,4 Shih-Chieh Hsu,7 Giuseppe Iacobucci,4 Enrique Kajomovitz,8 Felix Kling,5 Susanne Kuehn,3 Lorne Levinson,9 Hidetoshi Otono,2 Brian Petersen,3 Osamu Sato,10 Matthias Schott,11 Anna Sfyrla,4 Jordan Smolinsky,5 Aaron M. Soffa,5 Yosuke Takubo,12 Eric Torrence,13 Sebastian Trojanowski,14,15 and Gang Zhang16
We are grateful to the ATLAS SCT project and the LHCb Calorimeter project for letting us use spare modules as part of the FASER experiment. In addition, FASER gratefully acknowledges invaluable assistance from many people, including the CERN Physics Beyond Colliders study group; the LHC Tunnel Region Experiment (TREX) working group; Rhodri Jones, James Storey, Swann Levasseur, Christos Zamantzas, Tom Levens, Enrico Bravin (beam instrumentation); Dominique Missiaen, Pierre Valentin, Tobias Dobers (survey); Jonathan Gall, John Osborne (civil engineering); Caterina Bertone, Serge Pelletier, Frederic Delsaux (transport); Francesco Cerutti, Marta Sabaté-Gilarte, Andrea Tsinganis (FLUKA simulation and background characterization); Pierre Thonet, Attilio Milanese, Davide Tommasini, Luca Bottura (magnets); Burkhard Schmitt, Christian Joram, Raphael Dumps, Sune Jacobsen (scintillators); Dave Robinson, Steve McMahon (ATLAS SCT); Yuri Guz (LHCb calorimeters); Salvatore Danzeca (Radiation Monitoring); Stephane Fartoukh, Jorg Wenninger (LHC optics), Michaela Schumann (LHC vibrations); Marzia Bernardini, Anne-Laure Perrot, Katy Foraz, Thomas Otto, Markus Brugger (LHC access and schedule); Simon Marsh, Marco Andreini, Olga Beltramello (safety); Stephen Wotton, Floris Keizer (SCT QA system and SCT readout); Liam Dougherty (integration); Yannic Body, Olivier Crespo-Lopez (cooling/ventilation); Yann Maurer (power); Marc Collignon, Mohssen Souayah (networking); Gianluca Canale, Jeremy Blanc, Maria Papamichali (readout signals); Bernd Panzer-Steindel (computing infrastructure); and Mike Lamont, Fido Dittus, Andreas Hoecker, Andy Lankford, Ludovico Pontecorvo, Michel Raymond, Christoph Rembser, Stefan Schlenker (useful discussions).
BACK UP
Note fitting work into LS2 schedule very complex.
No dust allowed in LHC tunnel in 2019 due to diode consolidation (means no digging)
Need to transport FASER to TI12 before the machine is cooled (mid-June 2020)
LAMPPOST LANDSCAPE

Mass Coupling Strength

Already Discovered

Weakly Interacting Light Particles

Strongly Interacting Heavy Particles

Impossible to Discover

ATLAS/CMS

FASER

10^{-6}

10^{-3}

1

MeV GeV TeV
THE LIFETIME FRONTIER

• Very popular, many interesting experiments: LHCb, Belle-II, NA62, SHiP, SeaQuest, MilliQan, MATHUSLA, Codex-b, and many others

• FASER: ForwArd Search ExpeRiment. “The acronym recalls another marvelous instrument that harnessed highly collimated particles and was used to explore strange new worlds.”
DARK PHOTON STATUS

- Low $\varepsilon \to$ fixed target constraints, high $\varepsilon \to$ collider, precision constraints
- But still lots of open parameter space with $m_{A'} > 10$ MeV
  $\varepsilon \sim 10^{-6} - 10^{-3}$
- E.g., 2 representative model points: $(m_{A'}, \varepsilon) = (20$ MeV, $10^{-4})$
  $(100$ MeV, $10^{-5})$
FASER IN SITU

particles from IP1
To avoid parasitic collisions and beam-beam effects in the common beampipe close to the IP, the LHC runs with a crossing-angle

- The half crossing angle is ~150μrad, which moves the collision axis by ~7.5cm at the FASER location
- Such a change reduces the signal acceptance in FASER by ~25%
- Leads to very small changes in physics sensitivity
Sensitivity basically unchanged when comparing production with different generators, and scale choices.
FASER LHCC DOCUMENTS

TECHNICAL PROPOSAL

FASER

FORWARD SEARCH EXPERIMENT AT THE LHC


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Executive Summary

FASER is proposed small and inexpensive experiment designed to search for light, weakly-interacting particles at the LHC. Such particles are dominantly produced along the beam collision axis and may be long-lived, traveling hundreds of meters before decaying. To exploit both of these properties, FASER is to be located along the beam collision axis, 800 m downstream from the ATLAS interaction point, in the unused central tunnel T15. We propose that FASER be installed in this position and in time to collect data from Run 3 of the 14 TeV LHC. FASER will detect new particles that decay within a cylindrical volume with radius $r = 10$ m and length $L = 1.5$ m. With these small dimensions, FASER will exploit the LHC's existing physics program, extending its discovery potential to a host of new particles, including dark photons, axion-like particles, and other CP-odd scalars. A FASER simulation and analysis estimate have confirmed that numerous potential backgrounds are highly suppressed at the FASER location, and the first in situ measurements are currently underway. We describe FASER's location and discovery potential, its target signal and backgrounds, the detector's layout and components, and the experiment's preliminary cost estimate, funding, and timeline.
ASSUMPTIONS FOR OTHER EXPTS LIMITS

NA62 assumes $3.9 \times 10^{17}$ protons on target (POT) while running in a beam dump mode that is being considered for LHC Run 3 [16]; SeaQuest assumes $1.44 \times 10^{18}$ POT, which could be obtained in two years of parasitic data taking and requires additionally the installation of a calorimeter [12, 17]; the proposed beam dump experiment SHiP assumes $\sim 2 \times 10^{20}$ POT collected in 5 years of operation [16, 18]; Belle-II and LHCb assume the full expected integrated luminosity of $50 \text{ ab}^{-1}$ [19] and $300 \text{ fb}^{-1}$ [20, 21], respectively.


HPS limits taken from talk:
‘First Results from the Heavy Photon Search Experiment’ at ICHEP 2018
ASSUMPTIONS FOR OTHER EXPTS LIMITS

\[ m_{A'} [\text{GeV}] \]

\[ \epsilon \]

\[ \times 10^{-2} \]

\[ \times 10^{-3} \]

\[ \times 10^{-4} \]

\[ \times 10^{-5} \]

\[ \times 10^{-6} \]

\[ \times 10^{-7} \]

LHCb

LHCb \( D' \)

Belle-II

HPS

SeaQuest

NA62

LDMX

FASTER

FASTER 2

SHiP

MATHUSLA
Detector Support

Preliminary conceptual design:

Design/construction by DPNC mechanics team
Tracker alignment issues

Momentum resolution will be limited by the relative alignment of the 3 tracking stations in the bending plane. Significant rate of muons going through FASER tracker, but since we don’t know their momentum they can not be used to constrain this alignment (no standard candles (Z, J/psi etc..) in FASER. Since we use a permanent magnet we cannot use the trick (used in ATLAS MS) of taking straight track data with the field off to constrain the alignment. A 100um precision of the relative position of the tracking stations in the bending plane, leads to 100% uncertainty on the momentum for track momenta above ~650 GeV.

For FASER physics good track momentum resolution not needed, but of course for many reasons (background measurements, auxiliary physics measurements etc..) we want as good resolution as possible.
Transport / Installation issues

FASER components need to be carried over the LHC machine, and the QRL He cryo line, to get to TI12. Limits when this can be done, and requires installing protection.
OTHER PRODUCTION MECHANISMS

- Consider $\pi^0$ decay, $\eta$ decay, dark bremsstrahlung

- Results for 1st model point: $(m_{A'}, \varepsilon) = (20 \text{ MeV}, 10^{-4})$

- From $\pi^0 \rightarrow \gamma A'$, $E_{A'} \sim E_\pi / 2$ (no surprise)
- But note rates: even after $\varepsilon^2$ suppression, $N_{A'} \sim 10^8$ ;
STRAY MAGNETIC FIELD

• More detailed calculation of stray field, also going to larger distance
  – 3mT limit (for signage at CERN) always within 50cm of magnet centre (so enclosed in trench, does not impact access)

inside magnet
outside magnet

5cm outside magnet opening

1mT field 50cm from magnet centre
POSSIBLE FUTURE UPGRADE - FASER 2

- A potential upgraded detector for HL-LHC running, would increase sensitivity further
- Increasing detector radius to 1m would allow sensitivity to new physics produced in heavy meson (B, D) decays increasing the physics case beyond just the increased luminosity

FASER 2 therefore becomes very strong compared to low energy experiments for certain models (dark Higgs), due to large B/D production rates at LHC: $N_B/N_\pi \sim 10^{-2}$ ($\sim 10^{-7}$ at beam dump expts)
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