FASER: ForwArd Search ExpeRiment at the LHC

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University of Sheffield
for the FASER Collaboration

DMUK meeting
King’s College London, April 11, 2019

arXiv: 1708.09389; 1710.09387; 1801.08947; 1806.02348 (PRD,with J.L.Feng, I.Galon, F.Kling)
   arXiv:1811.12522 Physics case
arXiv:1901.04468 Input to the European Particle Physics Strategy
FASER APPROVAL

FASER: CERN approves new experiment to look for long-lived, exotic particles

The experiment, which will complement existing searches for dark matter at the LHC, will be operational in 2021

5 MARCH, 2019 | By Cristina Agrigoroae

related articles

[Symmetry: Dimensions of Particle Physics]
[Physics Today]
The FASER Collaboration: 36 collaborators, 16 institutions, 8 countries

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OUTLINE

• Motivation – light mediators and dark matter

• FASER: ForwArd Search ExpeRiment at the LHC (idea, basic detector design)

• Remarks about FASER physics program
  -- dark photons,
  -- light scalars,
  -- inelastic dark matter,
  -- axion-like particles,
  -- SM neutrinos

• Background: simulations & in-situ measurements

• Concluding remarks
MOTIVATION

heavy and strongly-coupled new physics e.g. SUSY, extra dimensions, ...
here also missing energy searches for heavy WIMP DM, magnetic monopoles,...

Light and very weakly coupled new physics:
-- requires large „luminosities“ (statistics)
-- new particles decay back to SM, but with highly displaced vertices
-- SM BG needs to be highly suppressed

Light DM landscape
LIGHT MEDIATORS – DM RELIC DENSITY

Generalized WIMP miracle:
\[ \Omega_{DM}h^2 \sim \frac{m^2}{g^4} \sim 0.1 \quad g \ll g_{weak} \Rightarrow m \ll m_{weak} \]

DM freeze-out

Light mediators: dark photon, dark scalars, …

L. Roszkowski, E.M. Sessolo, ST, 1707.06277

sub GeV-Scale MEDIATORS & LIGHT DM EXPERIMENTS & OBSERVATIONS

Dark matter self interactions
M. Kaplinghat, S. Tullin, H.-B. Yu, 1508.03339

Combined fit
- 95% CL
- 99% CL

Search for light mediators at colliders

Light DM direct detection
M. J. Dolan, F. Kahlhoefer, C. McCabe, 1711.09906

but also e.g. NA62
and many proposed exps e.g. Codex-b, MATHUSLA, SHiP, ...
FASER - IDEA

FASER – newly proposed, small (~0.05 m³) and inexpensive (~1M$) experiment detector to be placed few hundred meters downstream away from the ATLAS IP to harness large, currently „wasted” forward LHC cross section

\[ \sigma_{\text{inel}} \sim 75 \text{ mb}, \text{ e.g., } N_\pi \sim 10^{17} \text{ at } 3 \text{ ab}^{-1} \]

(for comparison \( \sigma \sim \text{fb} - \text{pb}, \text{ e.g., } N_H \sim 10^7 \text{ at } 300 \text{ fb}^{-1} \) in high-p_T searches)

FASER will complement ATLAS/CMS by searching for highly-displaced decays of new Light Long-Lived Particles

(part of Physics Beyond Colliders Study Group at CERN)
FASER LOCATION – TUNNEL TI12

- location in a side tunnel TI12 (former service tunnel connecting SPS to LEP)
- L ~ 485m away from the IP along the beam axis
- space for a **5-meter-long** detector
- precise position of the beam axis in the tunnel up to **mm precision** (CERN Engineering Dep)
- corrections due to beam crossing angle (for ~300μrad the displacement is ~7-8 cm)
TUNNEL TI12

new physics (hidden in the dark)

main LHC tunnel
BASIC DETECTOR LAYOUT

- 2 stages of the project:
  - **FASER 1**: \( L = 1.5 \text{ m}, R = 10 \text{ cm}, V = 0.05 \text{ m}^3, 150 \text{ fb}^{-1} \) (Run 3) (above layout)
  - **FASER 2**: \( L = 5 \text{ m}, R = 1 \text{ m}, V = 16 \text{ m}^3, 3 \text{ ab}^{-1} \) (HL-LHC)

Recycling existing spare modules:
- ATLAS SCT modules (Tracker)
- LHCb ECAL modules (Calorimeter)

Thank you !!!
FASER
PHYSICS
EXAMPLE OF LHC/FASER KINEMATICS

LLP FROM PION PRODUCTION AT THE IP

Soft pions going towards high-$p_T$ detectors:
- produced LLPs would be too soft for triggers
- large SM backgrounds

Hard pions highly collimated along the beam axis since their $p_T \sim \Lambda_{QCD}$ e.g. for $E_{\pi^0} \geq 10$ GeV
- $\sim 1.7\%$ of $\pi^0$s go towards FASER
- $\sim 24\%$ of $\pi^0$s go towards FASER 2

This can be compared to the angular size of both detectors with respect to the total solid angle of the forward hemisphere ($2\pi$):
- $\sim (2 \times 10^{-6})\%$ for FASER
- $\sim (2 \times 10^{-4})\%$ for FASER 2

LLPs produced from B mesons in FASER 2
- $p_T \sim m_B$ larger angular spread
- target for FASER 2

at FASER energies: $N_B/N_\pi \sim 10^{-2}$
- $10^{-7}$ for typical beam dumps
**DARK PHOTON**

- (broken) dark $U(1)$ gauge group,
- kinetic mixing with the SM photon: $\epsilon F_{\mu\nu} F'_{\mu\nu}$,
- after field redefinition:
  $\mathcal{L} \supset -\frac{1}{4} F_{\mu\nu} F'_{\mu\nu} - \frac{1}{4} F'_{\mu\nu} F'_{\mu\nu} + \frac{1}{2} m_{A'}^2 A'_\mu A'^\mu + \sum f (i \not{\partial} - \epsilon e q f A') f$
- production: $\pi^0$ and $\eta$ decays, bremsstrahlung, direct production in $q\bar{q}$ scatterings
- decays: dominantly into $e^+e^-$ and $\mu^+\mu^-$ up to $\sim 500$ MeV, then various hadronic decay modes

A' as a DM-SM mediator

\[ \bar{d} = \frac{1}{\Gamma_{A'}} \gamma_{A'} \beta_{A'} \approx (80 \text{ m}) B_e \left[ \frac{10^{-5}}{\epsilon} \right]^2 \left[ \frac{E_{A'}}{\text{TeV}} \right] \left[ \frac{100 \text{ MeV}}{m_{A'}} \right]^2 \]

\( \text{e.g. for } m_{A'} \sim m_\chi \) we obtain \( \langle \sigma v \rangle \sim \epsilon^2 \alpha D \left( m_{A'} \right)^2 \)

requiring \( \langle \sigma v \rangle \sim \alpha^2_{\text{weak}} / m^2_{\text{weak}} \) and putting \( \alpha D \sim \alpha^2_{\text{weak}} \)

one obtains \( \epsilon \sim m_{A'}/m_{\text{weak}} \sim 10^{-3}-10^{-5} \) for \( m_{A'} \sim 1-100 \text{ MeV} \)

**FASER 2** comparable to proposed large SHiP detector

\[ N_{\text{sig}} \propto \mathcal{L}_{\text{int}}^\text{int} \epsilon^2 e^{-L_{\text{min}}/\bar{d}} \quad \text{for} \quad \bar{d} \ll L_{\text{min}} \]

no of events grows exponentially with a small shift in $\epsilon$
DARK HIGGS BOSONS

- Dark Higgs boson: additional hidden real scalar field $\phi$,
- often adopted phenomenological parametrization:
  \[ \mathcal{L} \supset -m_{\phi}^2 \phi^2 - \sin \theta \frac{m_{\phi}}{v} \phi \bar{f} f - \lambda v h \phi \phi \]
- Higgs-like couplings suppressed by $\theta^2$,
- production: $B$ and $K$ decays, $h \rightarrow \phi \phi$, 
- decays: into the heaviest kinematically allowed states: $\mu^+ \mu^-$, $\pi \pi$, $KK$, ...

- at FASER energies: $N_B/N_{\pi} \sim 10^{-2}$ ($10^{-7}$ for typical beam+dumps)
- Typical $p_T \sim m_B \rightarrow$ improved reach for FASER 2 ($R=1m$)

Dark Higgs-DM portal

\[ \mathcal{L} \supset \frac{1}{2} \kappa \phi \bar{X} X \]

$\langle \sigma v \rangle \sim \kappa^4 \rightarrow \kappa$ fixed by relic density
**SELECTED OTHER MODELS**

**Inelastic DM**

Pseudo-Dirac pair $\chi_1$ and $\chi_2$ nearly degenerate in mass

$A'$-portal, dominant off-diagonal coupling to $A'$

$$\mathcal{L} \supset i e_D A'_\mu \bar{\chi}_1 \gamma^\mu \chi_2 + \mathcal{O}(\delta_\eta, \xi/m_D)$$

Production goes through $A'/Z$, $pp \rightarrow A' \rightarrow \chi_1 \chi_2$

$\chi_2$ decays are delayed by adjusting the mass splitting $\Delta$

→ up to 100s of events in FASER

reach can go up to $m_{A'} = 3m_1 > 30\text{GeV}$!

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**ALPs with di-photon coupling**

Fermionic iDM, $m_{A'} = 3m_1$, $\Delta = 0.05$, $\alpha_D = 0.1$

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A. Berlin, F. Kling, 1810.01879, PRD 99 (2019) no.1, 015021

1806.02348, PRD 98 (2018) no.5, 055021
SM NEUTRINOS IN FASER

Ideas currently explored:

1) Few cm thick lead plate will be put between several front veto layers for BG veto purposes (in front of FASER)

Incoming neutrinos can CC interact inside the lead plate producing muon with no counterpart in layers in front of the plate

Potentially hundreds of events in FASER

Measurement of the neutrino CC scattering cross section for $E_\nu \sim \text{TeV}$

2) Employing larger neutrino detector in front of FASER – additional information about kinematics (e.g. measurements of $\nu_\tau$)
SM BACKGROUNDS
BACKGROUNDs – SIMULATIONS (FLUKA)

Spectacular signal:
-- two opposite-sign, high energy (few hundred GeV) charged tracks,
-- that originate from a common vertex inside the decay volume,
-- and point back to the IP (+no associated signal in a veto layer in front of FASER),
-- and are consistent with bunch crossing timing.

• Neutrino-induced events: low rate

• The radiation level in TI18 is low (<10^{-2} Gy/year), encouraging for detector electronics

• Proton showers in a nearby Dispersion Suppressor lead to negligible BG after ~90m of rocks in front of FASER

• Muons coming from the IP – front veto layers

Expected trigger rate ~650 Hz

Other particles: detailed simulations, highly reduced rate (shielding + LHC magnets)

study by the members of the CERN FLUKA team:

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<th>Part. type</th>
<th>Cut T &gt; 100 GeV</th>
<th>Cut T &gt; 500 GeV</th>
<th>Cut T &gt; 1 TeV</th>
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<td>fluence per bunch crossing per cm^2</td>
<td>fluence rate (cm^2 s^{-1})</td>
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<td>µ^-</td>
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<td>~10^{-14}</td>
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<tr>
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<td>~10^{-12}</td>
<td>~10^{-6}</td>
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<tr>
<td>π</td>
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<td>~10^{-12}</td>
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<table>
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<th>Process</th>
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<td>µ</td>
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<tr>
<td>µ + γ_{brem}</td>
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</tr>
<tr>
<td>[µ + (γ_{brem} → e^+e^-)]</td>
<td>[7.4K]</td>
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<td>µ + EM shower</td>
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</tr>
<tr>
<td>µ + hadronic shower</td>
<td>21K</td>
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</table>
BACKGROUNDS – SIMULATIONS (2)

Cross section of the tunnel containing FASER

At FASER location:
   muon flux reduced along the beam collision axis (helpful role of the LHC magnets)
BACKGROUNDS – IN-SITU MEASUREMENTS

- Emulsion detectors – focusing on a small region around the beam axis (FASER location)
- TimePix Beam Lumi Monitors
- BatMons (battery-operated radiation monitors)

Analyses show that results are consistent with FLUKA simulations

PRACTICALLY ZERO BG SEARCH
FASTER IN POPULAR CULTURE

related article

Sebastian Trojanowski (University of Sheffield)
CONCLUSIONS

• Light Long-lived Particles (LLPs) – exciting new physics !!!

• **FASER** is a newly proposed, small and inexpensive experiment to be placed at the LHC to search for light long-lived particles to complement the existing experimental programs at the LHC, as well as other proposed experiments,

• FASER is fully approved by the CERN Research Board

• **FASER** would not affect any of the existing LHC programs and do not have to compete with them for the beam time etc.

• Rich physics prospects:
  - popular LLP models (dark photon, dark Higgs boson, GeV-scale HNLs, ALPs...),
  - Many connections to DM and cosmology (WIMPless miracle, light mediators, inelastic DM)
  - Possible first measurement of SM neutrinos in the LHC
  - Many other things not mentioned in the talk: invisible decays of the SM Higgs, ...

• Possible timeline:
  
  Install FASER 1 in LS2 (2019-20) for Run 3 (150 fb⁻¹)
  
  – R = 10 cm, L = 1.5 m, Target dark photons, B-L gauge bosons, ALPs, HNLs(τ)...

  Install FASER 2 in LS3 (2023-25) for HL-LHC (3 ab⁻¹)
  
  – R = 1 m, L = 5 m, Full physics program: dark vectors, ALPs, dark Higgs, HNLs...

New physics reach even after first 10 fb⁻¹ (end of 2021?)
BACKUP
INELASTIC P-P COLLISIONS

EPOS-LHC
HIDDEN SECTOR PORTALS

— new „hidden” particles are SM singlets
— interactions between the SM and „hidden” sector arise due to mixing through some SM portal

\[ \mathcal{L}_{\text{portal}} = \sum O_{\text{SM}} \times O_{\text{DS}} \]

B. Patt, F. Wilczek, 0605188
B. Batell, M. Pospelov, A. Ritz, 0906.5614

Renormalizable portals

<table>
<thead>
<tr>
<th>Portal</th>
<th>Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Photon, ( A_\mu )</td>
<td>(-\frac{\epsilon}{2\cos \theta_W} F'_{\mu \nu} B^{\mu \nu} )</td>
</tr>
<tr>
<td>Dark Higgs, ( S )</td>
<td>((\mu S + \lambda S^2) H^\dagger H)</td>
</tr>
<tr>
<td>Axion, ( a )</td>
<td>( \frac{a}{f_a} F_{\mu \nu} \tilde{F}^{\mu \nu} ), ( \frac{a}{f_a} G_{i, \mu \nu} \tilde{G}^{i, \mu \nu} ), ( \partial_{\mu} a \bar{\psi} \gamma^\mu \gamma^5 \psi )</td>
</tr>
<tr>
<td>Sterile Neutrino, ( N )</td>
<td>( y_N LHN )</td>
</tr>
</tbody>
</table>

PBC report, 1901.09966
DARK PHOTONS AT FASER – KINEMATICS

Monte Carlo fitted to experimental data (LHCf, ALFA)

- typically $p_T \sim \Lambda_{QCD}$
- for $E \sim \text{TeV}$ $p_T/E \sim 0.1 \text{ mrad}$
- even $\sim 10^{15}$ pions per $(\theta, p)$ bin

- $\pi^0 \rightarrow A'\gamma$
- high-energy $\pi^0$
  - collimated $A$'s
- $\varepsilon^2 \sim 10^{-10}$ suppression but still up to $10^5 A$'s per bin
- only highly boosted $A$'s survive until FASER $E_{A'} \sim \text{TeV}$
- further suppression from decay in volume probability
- still up to $N_{A'} \sim 100$ events in FASER, mostly within $r<20\text{ cm}$
COMPARISON – VARIOUS MC TOOLS

CRUCIAL CONTRIBUTION FROM LHC FORWARD PHYSICS AND DIFFRACTION WG

Overall agreement between MC and data

For large $p_z$: EPOS-LHC gives some overestimate

DPMJET 3.06

QGSJET II, SIBYLL lower estimates

THESE DISCREPANCIES HAVE VERY LITTLE IMPACT ON FASER SENSITIVITY

(see next slides)
Almost impreceivable differences in reach for various MC tools

$$N_{\text{sig}} \propto L^\text{int} \epsilon^2 e^{-L_{\text{min}}/\bar{d}} \quad \text{for} \quad \bar{d} \ll L_{\text{min}}$$

no of events grows exponentially with a small shift in $\epsilon$

FASER reach unaffected by a small offset as long as the beam collision axis goes through the detector
PROBING INVISIBLE DECAYS OF THE SM HIGGS

\[ \mathcal{L} = -\lambda v h \phi \phi \]

- trilinear coupling
  - invisible Higgs decays \( h \rightarrow \phi \phi \)

- far-forward region: efficient production via off-shell Higgs, \( B \rightarrow X_s h^*(\rightarrow \phi \phi) \)

- can extend the reach in \( \theta \) up to \( 10^{-6} \) for \( B(h \rightarrow \phi \phi) \approx 0.1 \)

- up to \(~100\)s of events
ALPS AT FASER – LHC AS A PHOTON BEAM DUMP

– similarly to the QCD axion, they can appear as pseudo-Nambu-Goldstone bosons in theories with broken global symmetries
– suppressed dim-5 couplings to gauge bosons \((1/\Lambda) a V^{\mu \nu} \tilde{V}_{\mu \nu}\)
– dim-5 couplings to fermions also allowed \((\partial_\mu a/\Lambda) \bar{f} \gamma_\mu \gamma_5 f\)
– interesting pheno scenario – dominant \(a \gamma \gamma\) coupling

B. Döbrich et al, JHEP 1602 (2016) 018

Photon beam dump (also „light shining through a wall”)

ALPs produced in the Primakoff process
INELASTIC DARK MATTER AT FASER

Pseudo-Dirac pair $\chi_1$ and $\chi_2$ nearly degenerate in mass

$$\mathcal{L} \supset m_D \eta \xi + \frac{1}{2} \delta_\eta \eta^2 + \frac{1}{2} \delta_\xi \xi^2 + \text{h.c.},$$

small mass splitting

$$\chi_1 \simeq \frac{i}{\sqrt{2}} (\eta - \xi)$$

$$\chi_2 \simeq \frac{1}{\sqrt{2}} (\eta + \xi), \quad \Delta \equiv \frac{m_2 - m_1}{m_1} \simeq \frac{\delta_\eta + \delta_\xi}{m_D} \ll 1$$

$A'$-portal, dominant off-diagonal coupling to $A'$

$$\mathcal{L} \supset ie_D A'_\mu \bar{\chi}_1 \gamma^\mu \chi_2 + \mathcal{O}(\delta_\eta, \delta_\xi/m_D)$$

Production $pp \rightarrow A' \rightarrow \chi_1 \chi_2$ goes through $A'/Z$:

- meson decays,
- dark Bremstrahlung,
- Drell-Yan

$\chi_2$ decays are delayed by adjusting $\Delta$:

$$\Gamma(\chi_2 \rightarrow \chi_1 \ell^+ \ell^-) \simeq \frac{4 e^2 \alpha_{em} \alpha_D \Delta^5 m_1^5}{15 \pi m_{A'}^4},$$

up to 100s of events in FASER reach can go up to $m_{A'} = 3m_1 > 30\text{GeV}$!

Nice example:
production and decay of LLPs decouple thanks to suppressed spectrum

FASER 2

Fermionic iDM, $m_{A'} = 3m_1$, $\Delta = 0.05$, $\alpha_D = 0.1$
HEAVY NEUTRAL LEPTONS AT FASER

Typical simplified approach:
- we focus on only one HNL leaving a signature in FASER
- we vary as free parameters

\[ m_N, \ U_{eN}, \ U_{\mu N}, \ U_{\tau N}, \ \text{where only one } U_{\ell N} \neq 0 \text{ at a time.} \]

**B and D meson decays** – we consider about \( \sim 20 \) production channels, dominant ones dictated by the CKM suppression, kinematics and fragmentation fractions

\[
\begin{align*}
D^0, \pm & \to N \ e^\pm \ K^{\mp,0,\ast}, \ D_s^\pm & \to N \ e^\pm, \ldots \\
B^0, \pm & \to N \ e^\pm \ D_{s}^{\mp,0,\ast}, \ B^\pm & \to N \ e^\pm, \\
B_c^\pm & \to N \ e^\pm, \ldots
\end{align*}
\]

Decay modes:
- \( \text{BR}(N \to 3\nu) \sim 10\% - 20\% \) invisible
- \( \text{BR}(N \to \nu l_1^+ l_2^-) \sim 20\% \) (BR(N \to \nu e^+ e^-) \sim few \ percent)
- \( \text{BR}(N \to \text{hadrons}) \sim 60\% - 70\%, \) various final states

**FASER 2**
- up to \( \sim 10^3 \) events for \( m_N \gtrsim m_D \)
- for \( m_N \lesssim m_D \) possible \( \sim 10^1 - 10^2 \) events
HEAVY NEUTRAL LEPTONS

• seesaw mechanism, e.g., for type-I seesaw

\[ \mathcal{L} = \mathcal{L}_{\text{SM}} + i \bar{\tilde{N}}_I \tilde{\Phi} \tilde{N}_I - F_{\alpha I} \bar{L}_\alpha \tilde{N}_I \tilde{\Phi} - \frac{1}{2} \tilde{N}_I^c M_I \tilde{N}_I + \text{h.c.} \]

• once Higgs gets vev, they mix with active (SM) neutrinos

Mixing angles:

\[ U_{eI}, U_{\mu I}, U_{\tau I} \]

• production in B and D meson decays

\[
\begin{align*}
D^{0,\pm} &\to N e^\pm K^{\mp,0,(*)},
D_s^{\pm} &\to N e^\pm, \ldots \\
B^{0,\pm} &\to N e^\pm D^{\mp,0,(*)},
B^\pm &\to N e^\pm, \\
B_c^\pm &\to N e^\pm, \ldots
\end{align*}
\]

• decay back into lighter SM particles

(Visible BR often 80-90%)
## MORE MODELS OF NEW PHYSICS

(table refers to the benchmark scenarios of the Physics Beyond Colliders CERN study group)

<table>
<thead>
<tr>
<th>Benchmark Model</th>
<th>Label</th>
<th>Section</th>
<th>PBC</th>
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<td>IV A</td>
<td>BC1</td>
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<td>IV C</td>
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Other models & FASER sensitivity studies e.g.:
- RPV SUSY (D. Drecks, J. de Vries, H.K. Dreiner, Z.S. Wang, 1810.03617)
- Inelastic dark matter (A. Berlin, F. Kling, 1810.01879)
Signal Detection in the Tracker

Signal is a pair of oppositely charged high-energy particles e.g. $1 \text{ TeV} \ A' \rightarrow e^+ e^-$

In the following we assume 100% detection efficiency for a better comparison with other experiments.

Ongoing work on full detector simulations

- 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
- 72 SCT modules needed for the full tracker
- 0.55T permanent dipole magnets based on the Halbach array design
  — LOS to pass through the magnet center
  — minimum digging to the floor in T112
  — minimized needed services (power, cooling)
- manufacture: CERN magnet group
- stray field around scintillator PMTs ~5mT shielding (mu-metal)
**FASER TRACKING STATIONS**

- 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!
- 72 SCT modules needed for the full tracker
- 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)
**FASER will have an ECAL:**

measuring the EM energy in the event (up to 1% accuracy in energy \( \sim 1 \text{ TeV} \))

**Will use 4 spare LHCb outer ECAL modules**
- Many thanks to LHCb Collaboration for allowing us to use these!
- 66 layers of lead/scintillator (2mm lead, 4mm plastic scintillator)
  - 25 radiation lengths long
  - no longitudinal shower information
  - Resolution will degrade at higher energy due to not containing full shower in calorimeter
- Scintillators used for vetoing charged particles entering the decay volume, for triggering and as a preshower
  - To be produced at CERN scintillator lab
  - Vetoing: achievable extremely efficient charged particle veto (eff>99.99%)
  - Trigger: also timing the signal with respect to timing of the $pp$ interactions
  - Preshower: thin radiator in front, photon showering (disentangling from $\nu$ interactions in ECAL)
MORE ABOUT TRACK SEPARATION

GEANT 4
FASER AND SURROUNDING LHC INFRASTRUCTURE

ATLAS Interaction Point (IP)

Strong LHC dipole magnets

TAN Neutral Particle Absorber ~140m away from the IP

FASER location tunnel TI12 ~480m away from the IP
FASER TIMELINE


...within ~1.5 year FASER grew to an international collaboration recognized at CERN

Currently: ~36 active members from ~16 institutions in ~8 countries,

Spokespersons: Jamie Boyd (CERN), Jonathan L. Feng (UC Irvine)

During LHC Run 2 (2018): detailed BG simulations (CERN Eng Dep) + in-situ measurements

Sep 2018: FASER Letter of Intent -- accepted by the LHC Committee

Dec 2018: Technical Proposal recommended by the LHC Committee for a full approval

Dec 2018/Jan 2019: fundings granted for the detector (Heisig-Simons and Simons foundations)

Mar 2019: FASER fully approved by the CERN Research Board

PLANS:

– Final detector design, manufacture, installation and commissioning during Long Shutdown 2 (ongoing work)

– Data taking during LHC Run 3 (2021-23)

– FASER 2 (major upgrade for HL-LHC)
POSSIBLE LOCATIONS (TI12 vs TI18)

- When designing the detector 2 main possible locations were considered: tunnels TI12 and TI18 on two sides of the ATLAS IP (~480m away from the IP)
- Both are former service tunnels connecting SPS and the main LHC tunnel
- Both are currently unused
- Both slope steeply upwards when leaving the main LHC tunnel (SPS is shallower than LHC)
- In both cases the line-of-sight (along the beam collision axis) is below the tunnel floor as it enters the tunnel, and then emerges from the floor
- Lowering of the floor up to 460mm is possible to maximize the detector length
  (CERN survey team)
- The tunnels do have identical geometry:
  - about 5m long detector can be fit in tunnel TI12
  - about 3m long detector can be fit in tunnel TI18
- Based on this the preferred location is the tunnel TI12
- BG measurements have been performed in both locations (below fluxes within 10 mrad)

<table>
<thead>
<tr>
<th></th>
<th>beam [fb⁻¹]</th>
<th>observed tracks [cm⁻²]</th>
<th>efficiency</th>
<th>normalized flux, all [fb cm⁻²]</th>
<th>normalized flux, main peak [fb cm⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TI18</td>
<td>2.86</td>
<td>18407</td>
<td>0.25</td>
<td>$(2.6 \pm 0.7) \times 10^4$</td>
<td>$(1.2 \pm 0.4) \times 10^4$</td>
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<tr>
<td>TI12</td>
<td>7.07</td>
<td>174208</td>
<td>0.80</td>
<td>$(3.0 \pm 0.3) \times 10^4$</td>
<td>$(1.9 \pm 0.2) \times 10^4$</td>
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<tr>
<td>FLUKA simulation, E≥100 GeV</td>
<td></td>
<td></td>
<td></td>
<td>$1 \times 10^4$</td>
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</tbody>
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