The Event Generator GenEx for CEP

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Central Exclusive Production at the LHC

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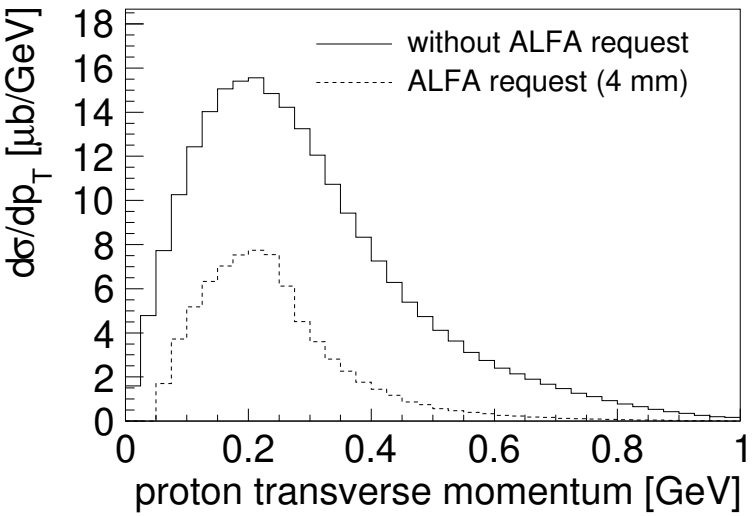
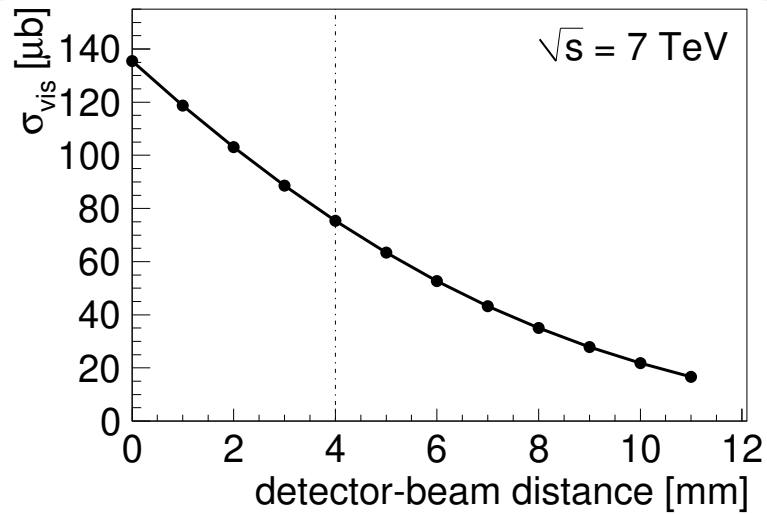
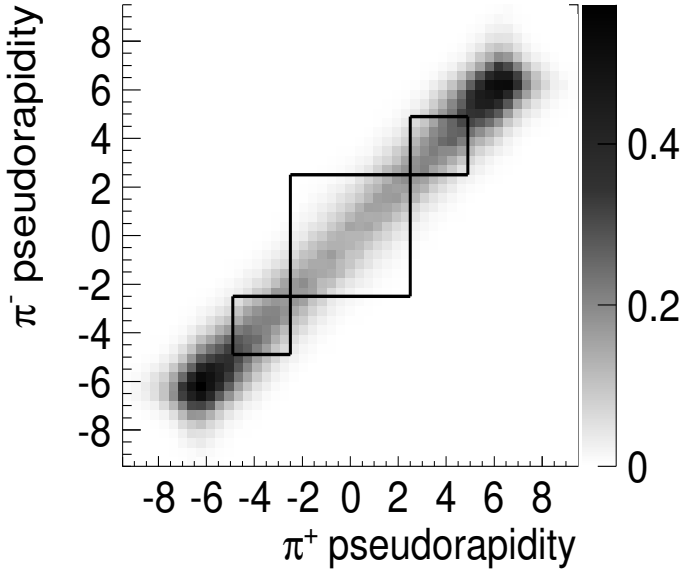
Motivation

- Exclusive meson production is possible to be measured by RHIC and LHC experiments.
- Monte Carlo generator is needed in order to include detector effects (acceptance, efficiency) in theory-data comparison.
- There are few MC generators available, *e.g.* SuperCHIC, DIME.
- We would like to introduce a tool complementary to the existing ones in terms of implemented processes and calculation methods.
- For now, implemented models are based mainly on work of P. Lebiedowicz, A. Szczurek & co.
- This includes:
  - non-resonant (continuum) pion and kaon pair production,
  - $f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_2(1270)$, $f_2'(1520)$ and ρ_0 particles and their decays into two pions or kaons.

Predictions for ALFA







Cross section visible in the ALFA detectors (both protons tagged) as a function of the distance between the detectors and the beam centre.

Majority of outgoing protons are in ALFA acceptance region.

Large correlation between pions pseudorapidity.

Should be measurable in ALFA!

Full analysis: Acta Physica Polonica B **42** (2011) 1861

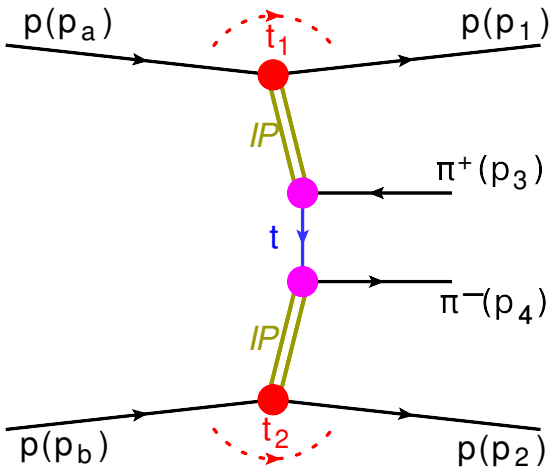
GenEx MC Generator

- GenEx – a C++ class structure for the construction of a Monte Carlo event generators which can produce unweighted events within relativistic phase space.
- Generator is self-adapting to the provided matrix element and acceptance cuts.

- Existing and planned features:
  - resonant and non-resonant exclusive meson production processes,
  - scalar, vector and tensor Pomeron,
  - pp and $p\bar{p}$ collisions,
  - spin (polarization) effects,
  - absorption and re-scattering corrections,
  - simple, user friendly interface,
  - output in formats usable by experiments (LesHouches, HEPMC, ...).

- First versions (basic features) are already available:
  - `https://github.com/rkycia/GenEx`,
  - `https://github.com/rkycia/GenExLight`.

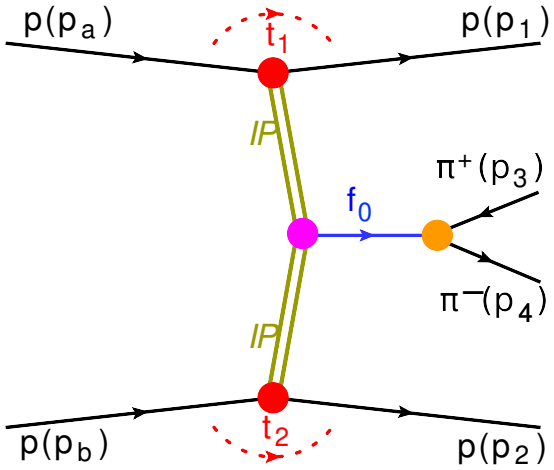
Process Type 1: Non-resonant Pion Pair Production



- $pp \to p\pi^+\pi^- p$ (continuum),
- model based on: Phys. Rev. D **93** (2016) 054015,
- off-shell pion exchanged in the t-channel,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$\mathcal{M}^{(\hat{t})}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(IPpp)}_{\mu_1\nu_1}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-Pomeron vertex
$i\Delta^{(IP)\mu_1\nu_1,\alpha_1\beta_1}(s_{13},t_1)\times$	Pomeron propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha_1\beta_1}(p_t,-p_3)\times$	Pomeron-pion vertex
$i\Delta^{(\pi)}(p_t)\times$	pion propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha_2\beta_2}(p_4,p_t)\times$	pion-Pomeron vertex
$i\Delta^{(IP)\alpha_2\beta_2,\mu_2\nu_2}(s_{24},t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(IPpp)}_{\mu_2\nu_2}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

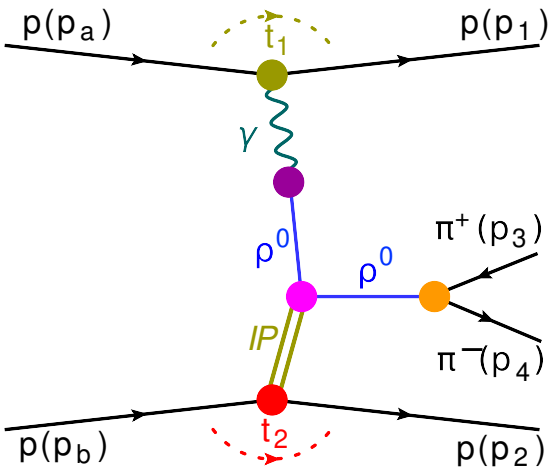
Process Type 2: Pion Pair Production via f_0 Resonance



- $pp \to p(f_0 \to \pi^+\pi^-)p$,
- model based on: Phys. Rev. D **93** (2016) 054015,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$\mathcal{M}^{(IPIP\to f_0\to\pi^+\pi^-)}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(IPpp)}_{\mu_1\nu_1}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-Pomeron vertex
$i\Delta^{(IP)\mu_1\nu_1,\alpha_1\beta_1}(s_1,t_1)\times$	Pomeron propagator
$i\Gamma^{(IPIPf_0)}_{\alpha_1\beta_1,\alpha_2\beta_2}(q_1,q_2)\times$	Pomeron-f_0 vertex
$i\Delta^{(f_0)}(p_{34})\times$	f_0 propagator
$i\Gamma^{(f_0\pi\pi)}(p_{34})\times$	f_0-pion vertex
$i\Delta^{(IP)\alpha_2\beta_2,\mu_2\nu_2}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(IPpp)}_{\mu_2\nu_2}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

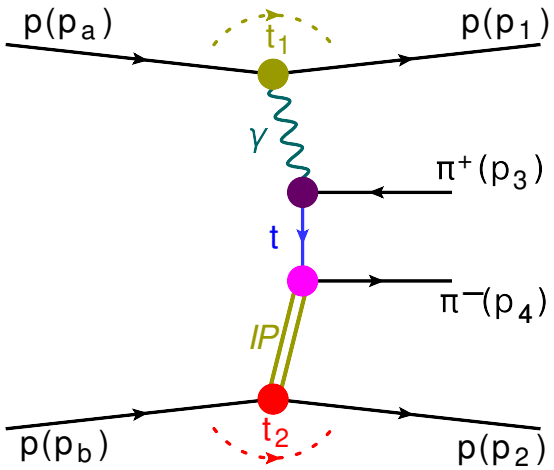
Process Type 3: ρ^0 Photoproduction



- $pp \to p\pi^+\pi^- p$ via $\gamma p \to (\rho^0 \to \pi^+\pi^-)p$,
- model based on: arXiv:1412.3677,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$\mathcal{M}^{(\gamma I\!P)}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(\gamma pp)}_{\mu}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-photon vertex
$i\Delta^{(\gamma)\mu\sigma}(q_1)\times$	photon propagator
$i\Gamma^{(\gamma\to\rho)}_{\sigma\nu}(q_1)\times$	photon-ρ vertex
$i\Delta^{(\rho)\nu\rho_1}(q_1)\times$	ρ propagator
$i\Gamma^{(I\!P\rho\rho)}_{\rho_2\rho_1\alpha\beta}(p_{34},q_1)\times$	ρ-Pomeron vertex
$i\Delta^{(\rho)\rho_2\kappa}(p_{34})\times$	ρ propagator
$i\Gamma^{(\rho\pi\pi)}_{\kappa}(p_3,p_4)\times$	ρ-pion vertex
$i\Delta^{(I\!P)\alpha\beta,\delta\eta}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(I\!Ppp)}_{\delta\eta}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

Process Type 4: Photon-induced Continuum



- $pp \to p\pi^+\pi^- p$,
- model based on: arXiv:1412.3677,
- off-shell pion exchanged in the t-channel,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$\mathcal{M}^{(t)}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(\gamma pp)}_{\mu}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-photon vertex
$i\Delta^{(\gamma)\mu\nu}(q_1)\times$	photon propagator
$i\Gamma^{(\gamma\pi\pi)}_{\nu}(p_t,-p_3)\times$	photon-pion vertex
$i\Delta^{(\pi)}(p_t)\times$	pion propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha\beta}(p_4,p_t)\times$	pion-Pomeron vertex
$i\Delta^{(IP)\alpha\beta,\delta\eta}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(IPpp)}_{\delta\eta}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

Process Type 5: Diffractive Bremsstrahlung

- Pomeron or photon induced process.
- Production described by models of *e.g.*:
  - Khoze-Lamsa-Orava-Ryskin, JINST **6** (2011) P01005,
  - Lebiedowicz-Szczurek, Phys. Rev. D **87** (2013) 114013.
- Implemented in *e.g.* GenEx MC generator (arXiv:1411.6035).
- Measurement idea:
  - measure protons in ALFA and photon in ZDC,
  - described in: [1] Eur. Phys. J. C **77** (2017) 216.

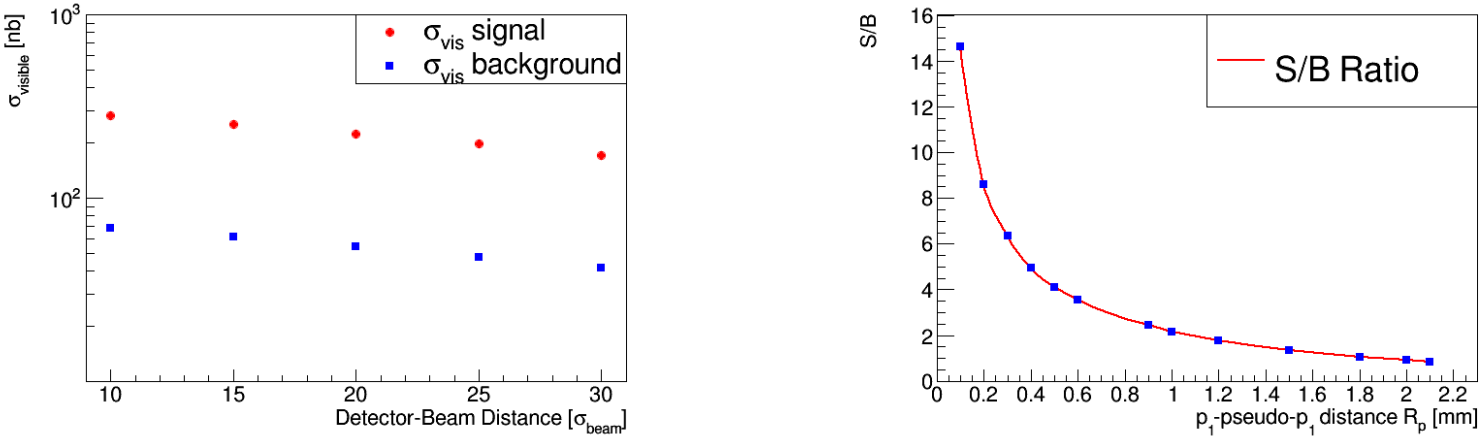
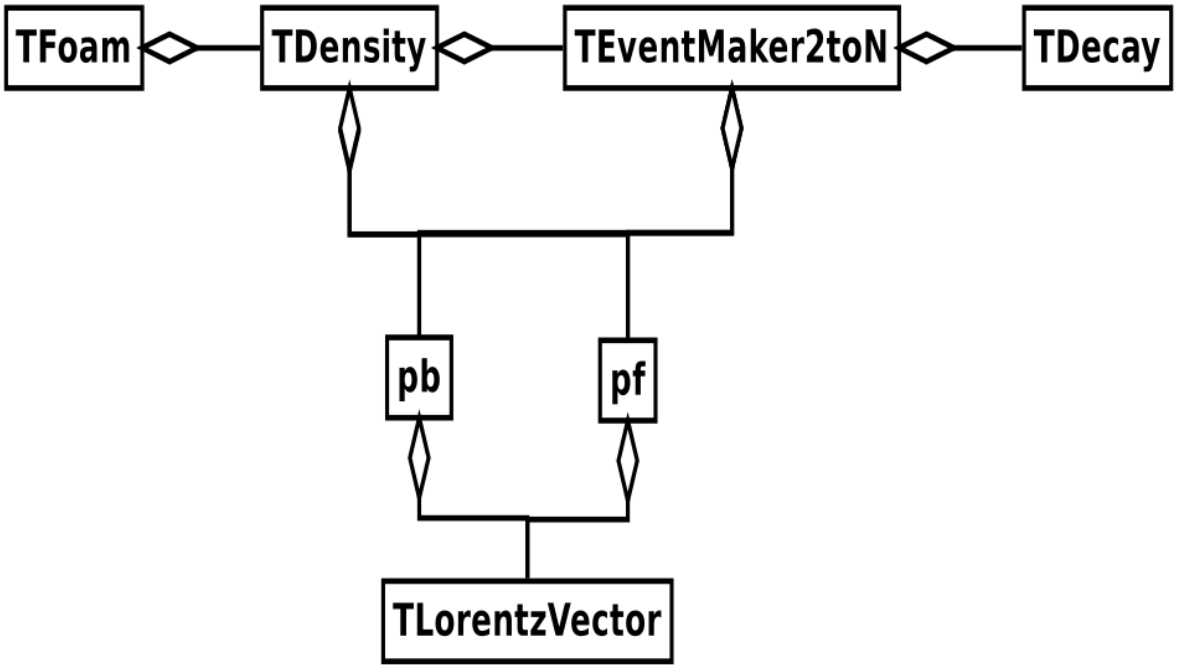


Fig. Predictions for ATLAS. **Left**: *visible cross-sections for signal and background as a function of beam-detector distance.* **Right**: *signal to background ratio. From [1].*

Generator Structure – Current Available Version



- *pb* and *pf* are event tables containing beam and final particles,
- TFoam – class of adaptive Monte Carlo simulator,
- TDensity – class with integrand function (calculated accordingly to a given event),
- TEventMaker2toN – generates two leading particles and a central blob which then is decayed by TDecay into $N-2$ remaining particles.

New Version – User Friendly Amplitude Implementation

Each vertex and propagator represented as class derived from corresponding base class:

- OScalar – scalar (*e.g.* Pion propagator)
- OVector – 4 el. vector (*e.g.* Proton-Photon vertex)
- OMatrix – 4 by 4 matrix (*e.g.* Proton-Pomeron vertex)
- OTensor4 – rank 4 tensor (*e.g.* Pomeron Propagator)

Overloaded operators (*, +, –), e.g.:

- OMatrix * OTensor4: $T_{ij} \cdot T^{ijkl} = T^{kl}$
- OTensor4 * OMatrix: $T^{ijkl} \cdot T_{kl} = T^{ij}$

Used tools: C++, ROOT (SVector, SMatrix, TLorentzVector classes).

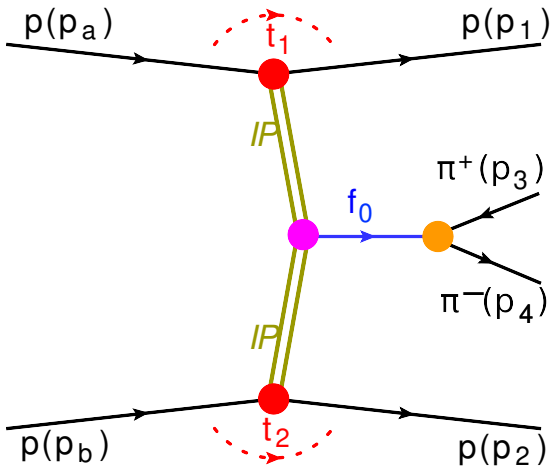
Class Implementation – Example

$$i\Delta^{(\mathbb{P})}_{\mu\nu,\kappa\lambda}(s,t) = \frac{1}{4s}\left(g_{\mu\kappa}g_{\nu\lambda} + g_{\mu\lambda}g_{\nu\kappa} - \frac{1}{2}g_{\mu\nu}g_{\kappa\lambda}\right)(-is\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t)-1}$$

```
class PropPom : public OTensor4 {
[...]

    for (int i = 0; i < 4; ++i)
      for (int j = 0; j < 4; ++j)
        for (int k = 0; k < 4; ++k)
          for (int l = 0; l < 4; ++l)
            result(i, j, k, l) = g(i, k) * g(j, l)
                                 + g(i, l) * g(j, k)
                                 - g(i, j) * g(k, l) / 2.0;

[..]
};
```

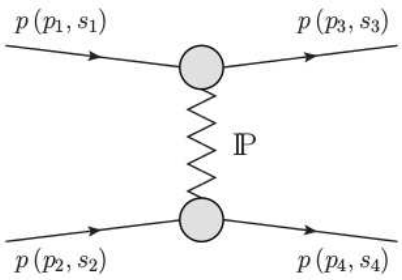
Amplitude Calculation – User's Perspective

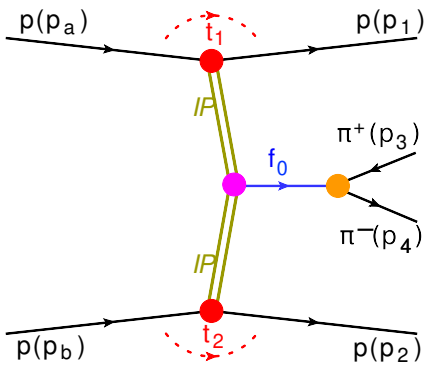
```
TLorentzVector pa, pb, p1, p2, p3, p4;
const std::complex<double> IU(0, 1);
[...]
double t1 = (pa-p1).Mag2();
TLorentzVector p34 = p3 + p4;
[...]
VtxPomProtProt V1(pa, p1, +1, -1);
VtxPomProtProt V2(pb, p2, +1, +1);
PropPom P1(s1, t1);
PropPom P2(s2, t2);

VtxPomPomf0 V3(q1, q2);
Propf0 P3(p34);
Vtxf0PiPi V4(p34);

std::complex<double> A;
A = -IU*V1*P1*V3*P3*V4*P2*V2;
```

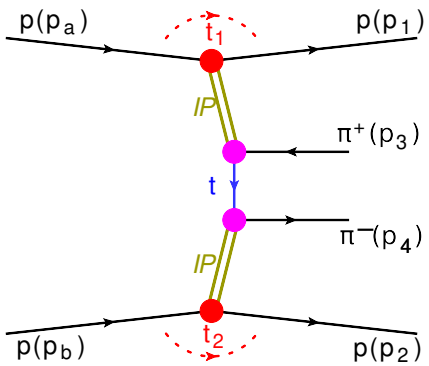


Current Status

- Tensor operations implemented
- Existing elements:
  - Pomeron–proton vertex
  - Pomeron propagator
  - Pomeron–pion vertex
  - Pion propagator
  - Pomeron–$f_0(980)$ vertex
  - $f_0(980)$ propagator
  - $f_0(980)$-pion vertex
- Existing processes:







- Next steps:
  - public working example with user manual,
  - find developers.

Summary

- Exclusive light meson production should be visible at LHC. Especially in data taken during special, high-β^* runs with forward detectors.

- A Monte Carlo generator containing continuum and resonances would be useful to understand data.
- One of such generators is GenEx.
- It contains the generator structure and pion/kaon continuum production processes.

- In the near future a new version will be published. It would allow to:
  - generate resonant production ($f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_2(1270)$, $f_2'(1520)$ and ρ_0),
  - spin (polarization) effects,
  - absorption and re-scattering corrections,
  - all in a user-friendly, simple and effective way!
- Manpower – new developers are searched for.

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4 STUDENTS

PAN

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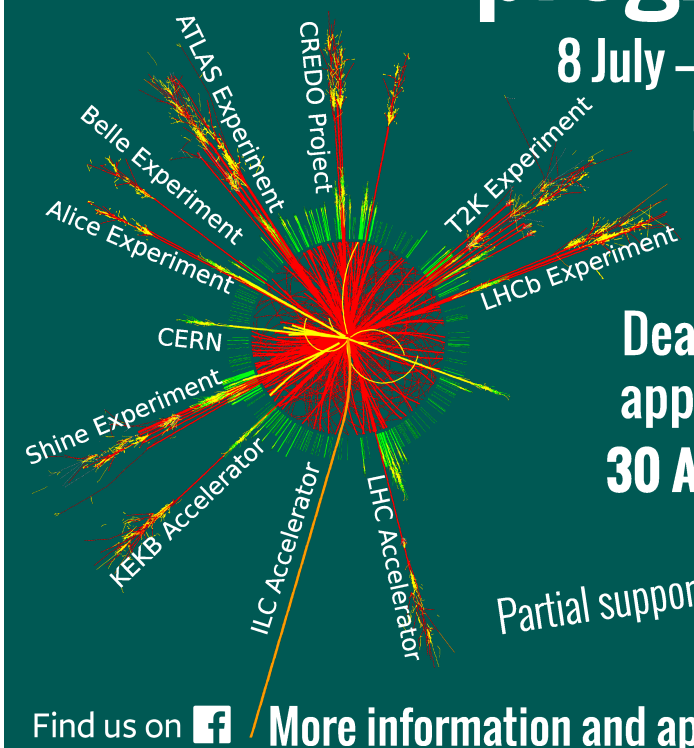

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