technische universität
dortmund

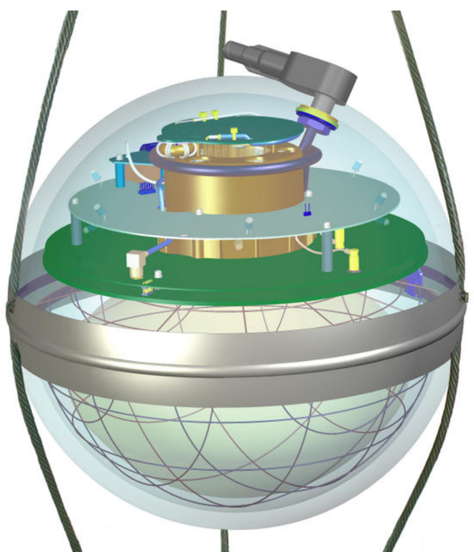
Experimentelle Physik Vb
Astroteilchenphysik

New Cross Section for Muon-Proton-Bremsstrahlung

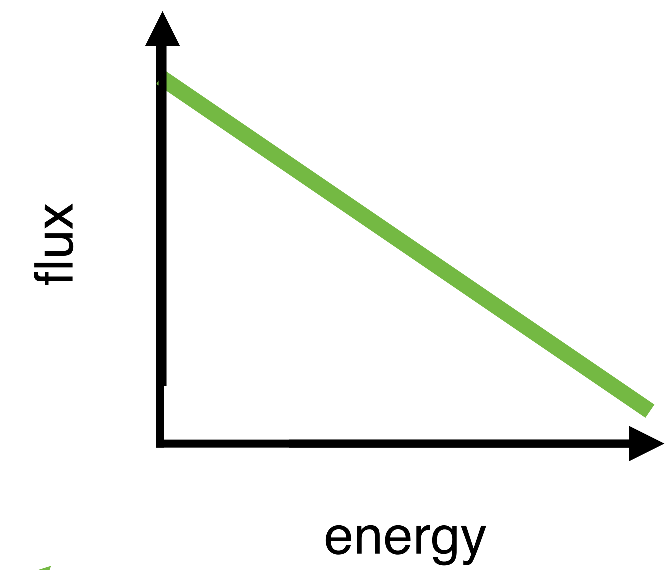
Thorben Menne
10.10.2014

IceCube Simulation

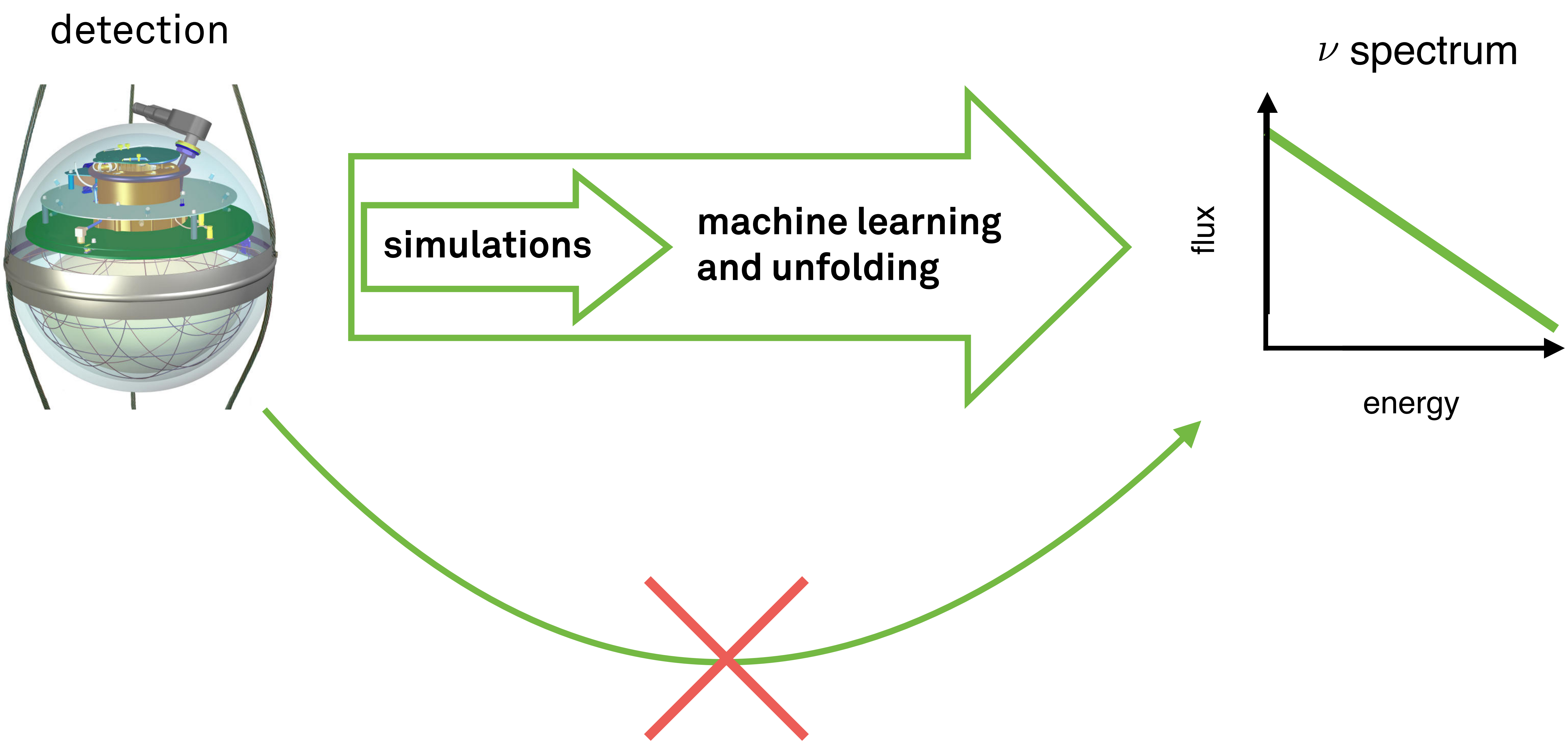
detection



ν spectrum

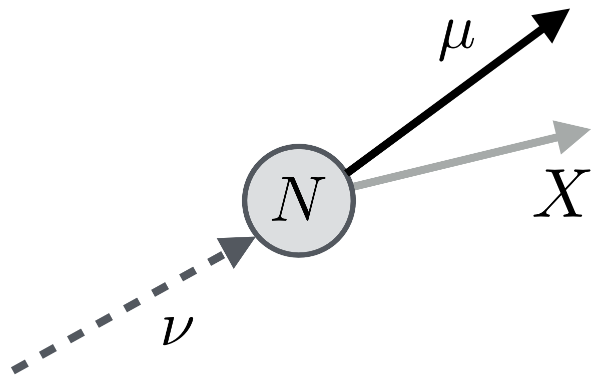


IceCube Simulation

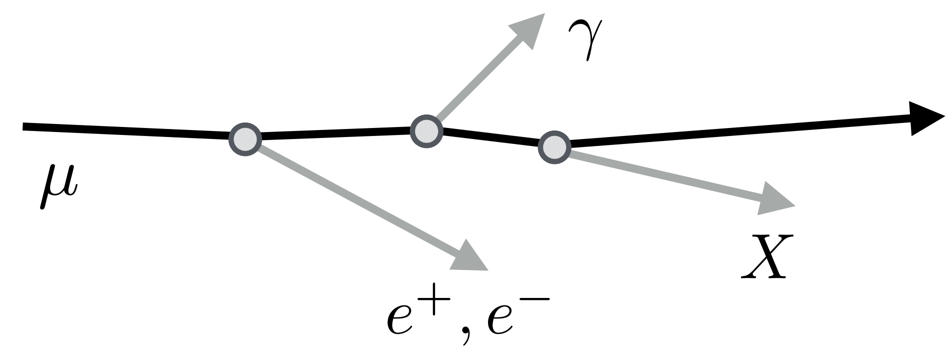


IceCube Simulation

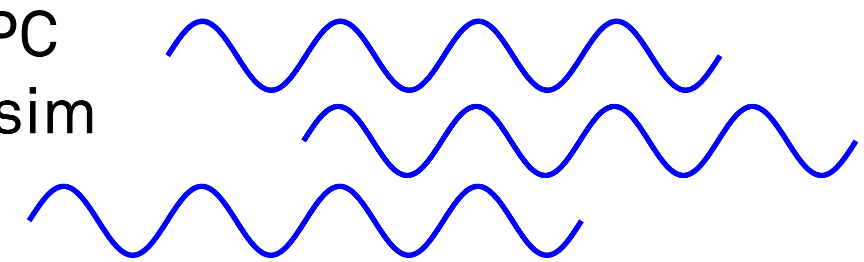
generators:
- NuGen
- CORSIKA



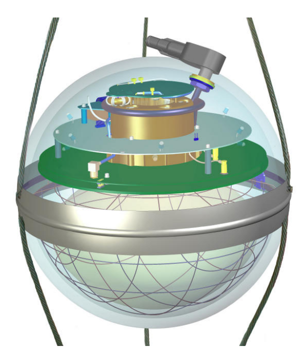
lepton propagator **PROPOSAL**



photon propagators:
- photonics
- PPC
- clsim



detector components:
- electrics
- trigger
- ...



PROPOSAL

PRopagator with **O**ptimal **P**recision and **O**ptimized **S**peed for **A**ll **L**eptons

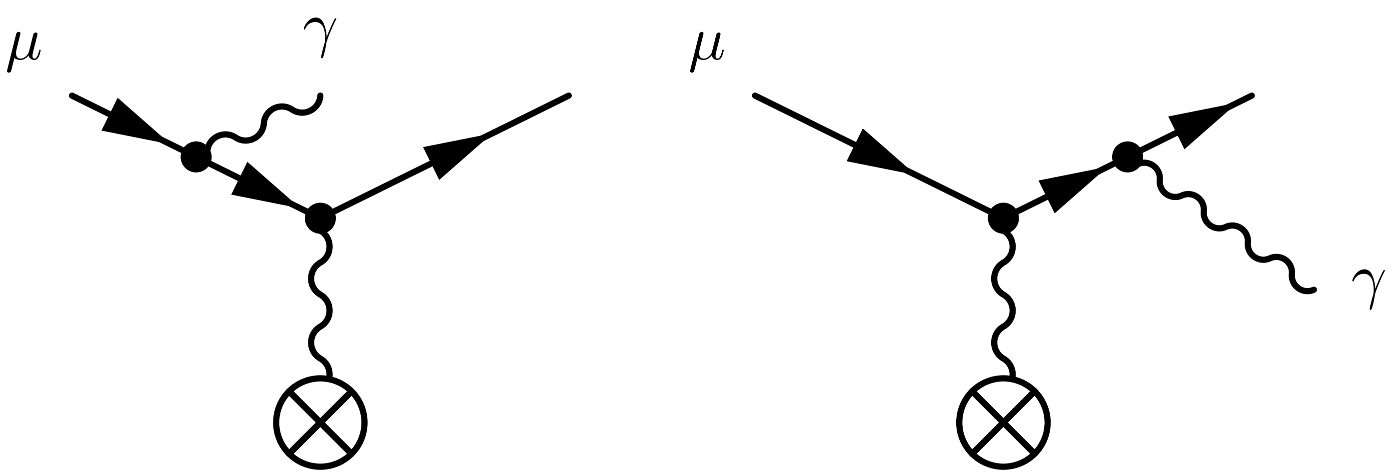
- ... **Optimal Precision** ...
  - aiming for exact simulation
  - small errors in cross sections necessary
- systematic errors higher than statistical ones
- cross sections for different interactions

$\mu A \to \mu A^+ e^-$	$\mu A \to \mu A e^+ e^-$	$\mu A \to \mu A \gamma$	$\mu N \to \mu N X$
ionisation	pair production	bremsstrahlung	photo nuclear

multiple models to choose from

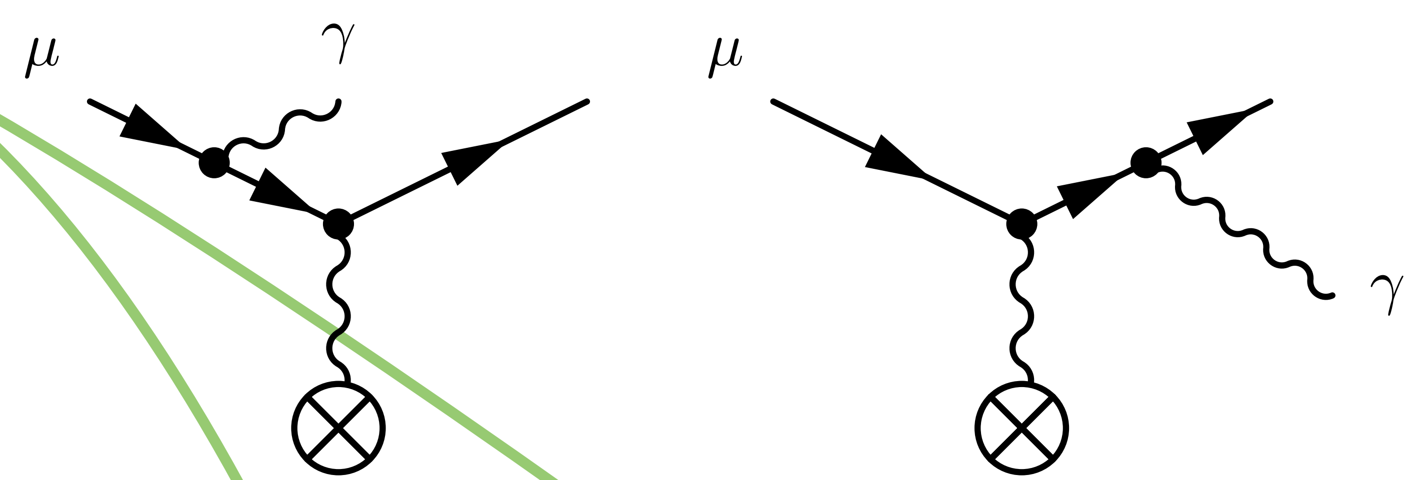
Bremsstrahlung Cross Sections in PROPOSAL

- 4 different parametrizations
- based on Bethe-Heitler formula, QED
- various corrections



Bremsstrahlung Cross Sections in PROPOSAL

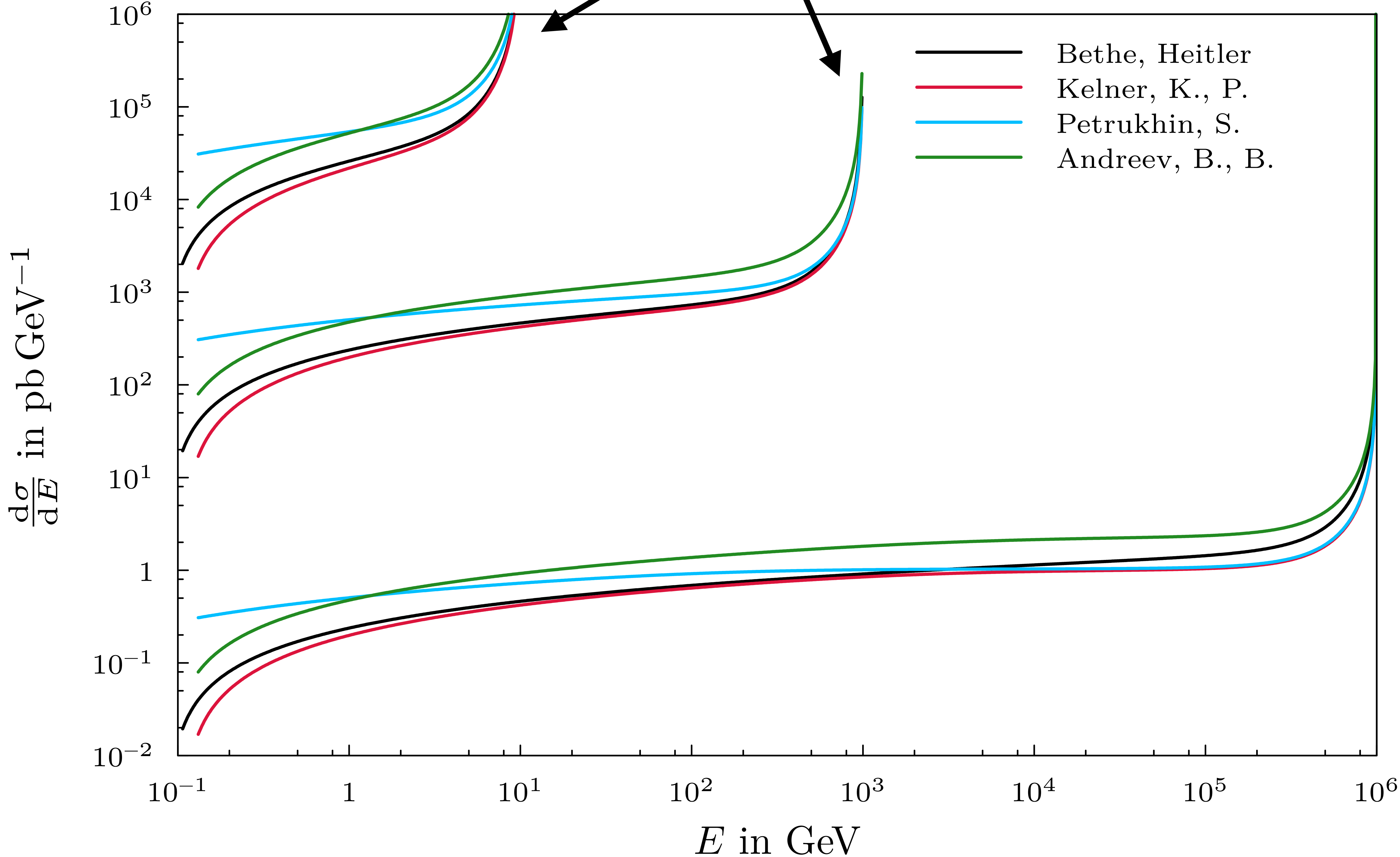
- 4 different parametrizations
- based on Bethe-Heitler formula
- various corrections
  - finite nucleus size
  - screening
  - nucleus excitation
  - coulomb correction



$$\frac{\mathrm{d}\sigma}{\mathrm{d}v} = \frac{4\alpha Z^2 e^4}{m_\mu^2}\frac{1}{v}\left((2-2v+v^2)\boxed{\phi_1(\delta)} - \frac{2}{3}(1-v)\boxed{\phi_2(\delta)}\right)$$

$$\delta = \frac{m_\mu^2 k}{2E_0(E_0-k)}$$

divergence due to $\omega \to 0$



New Cross Section

existing c.s. → **new c.s.**

existing c.s.

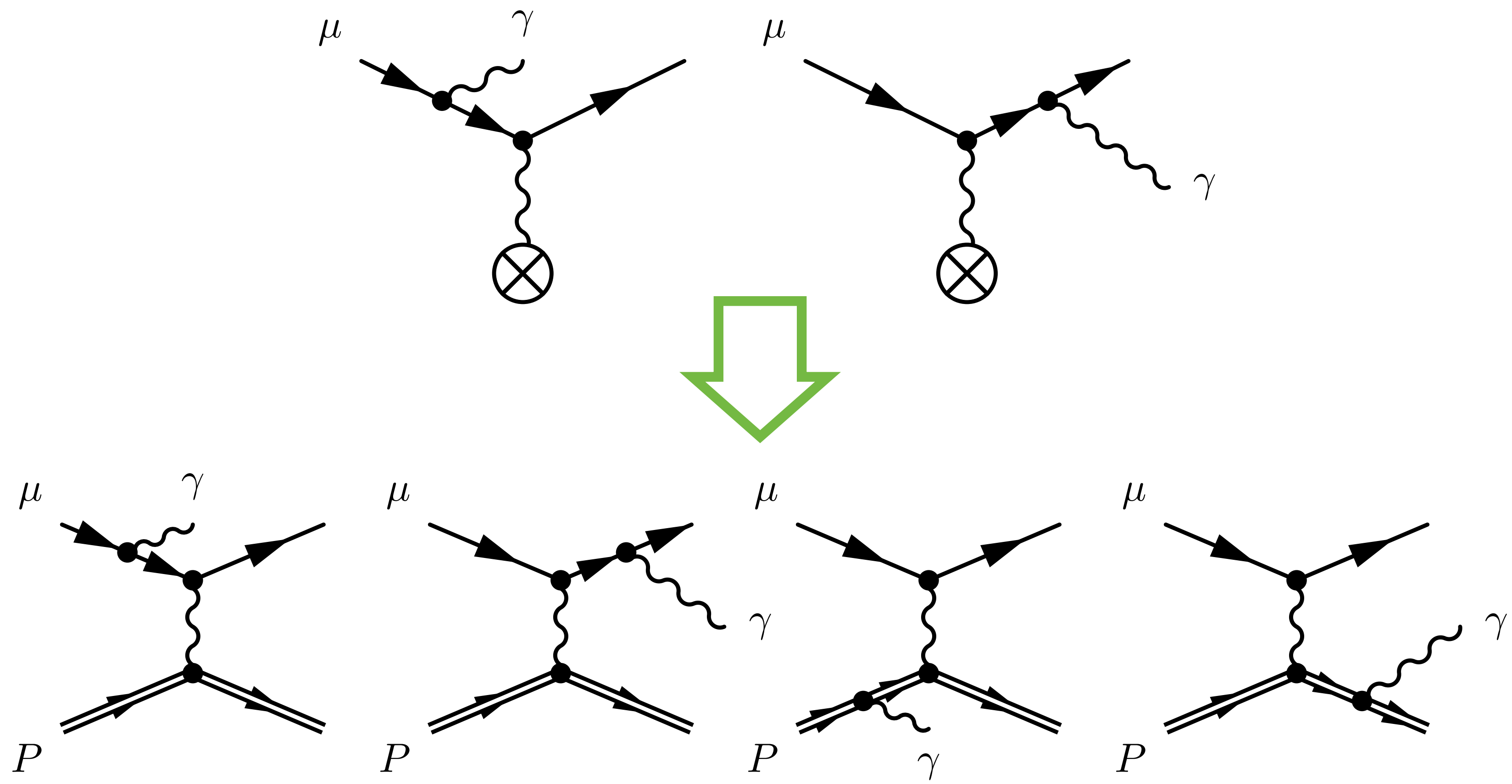
- static field
  - not Lorentz-invariant
- valid for very high energies only
- Thomas-Fermi form-factors

new c.s.

- dynamic field with recoil
  - explicit Lorentz-invariant
  - semi automatic calculation possible
- no kinematical approximations
- proton form-factors from 2013 measurements

New Cross Section

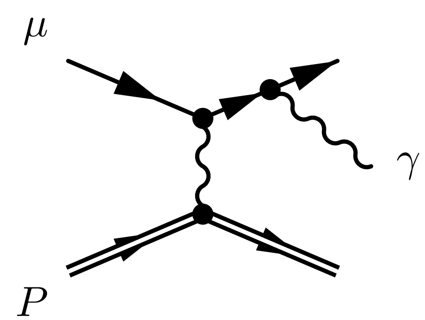
- effective proton-vertex function $\Gamma_\mu = F_1(q^2)\gamma_\mu + \frac{\mathrm{i}\sigma_{\mu\nu}q^\nu}{2M}F_2(q^2)$
- tree level QED calculation
- **find best working phase space**



Computer Aided Calculation

Mathematica

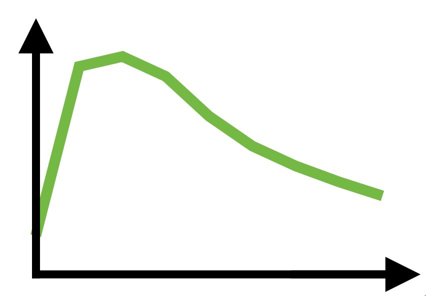
FeynArts
- topologies
- particles
- amplitude



FormCalc
- process amplitude
- indices, fermion chains, ...

$$u^{\alpha}\gamma^{\nu}_{\alpha\beta}\bar{u}^{\beta}$$

numerical calculation of cross section



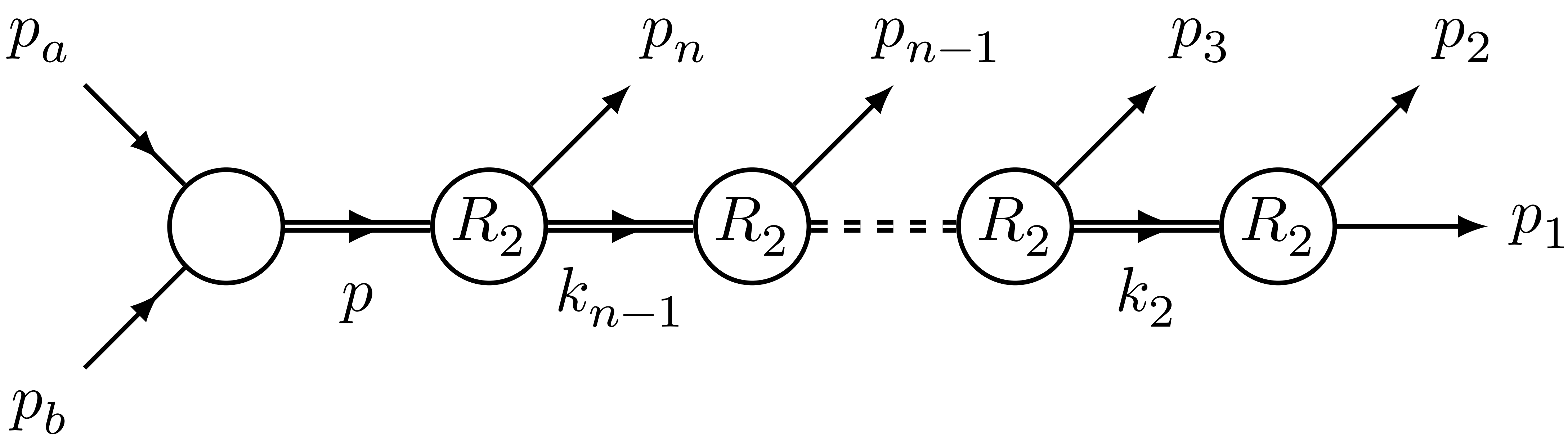
Fortran

Phase Space

First Approach

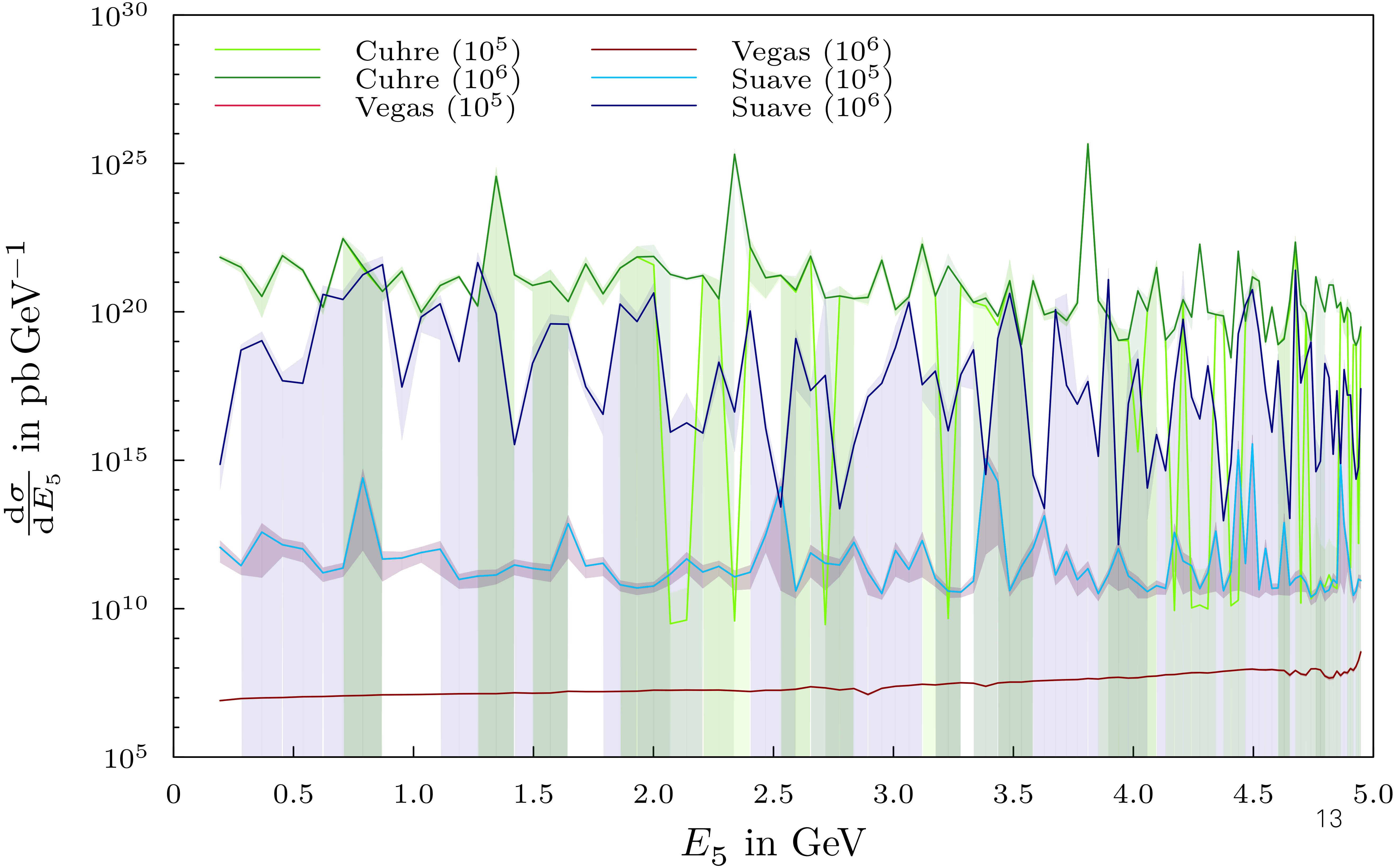
- recursively build up phase space

$$R_3 = \frac{1}{2\sqrt{s}} \int \mathrm{d}M_2\, \Omega_2\, \frac{p_3}{2} \int \mathrm{d}\Omega_1\, \frac{p_2}{2}$$

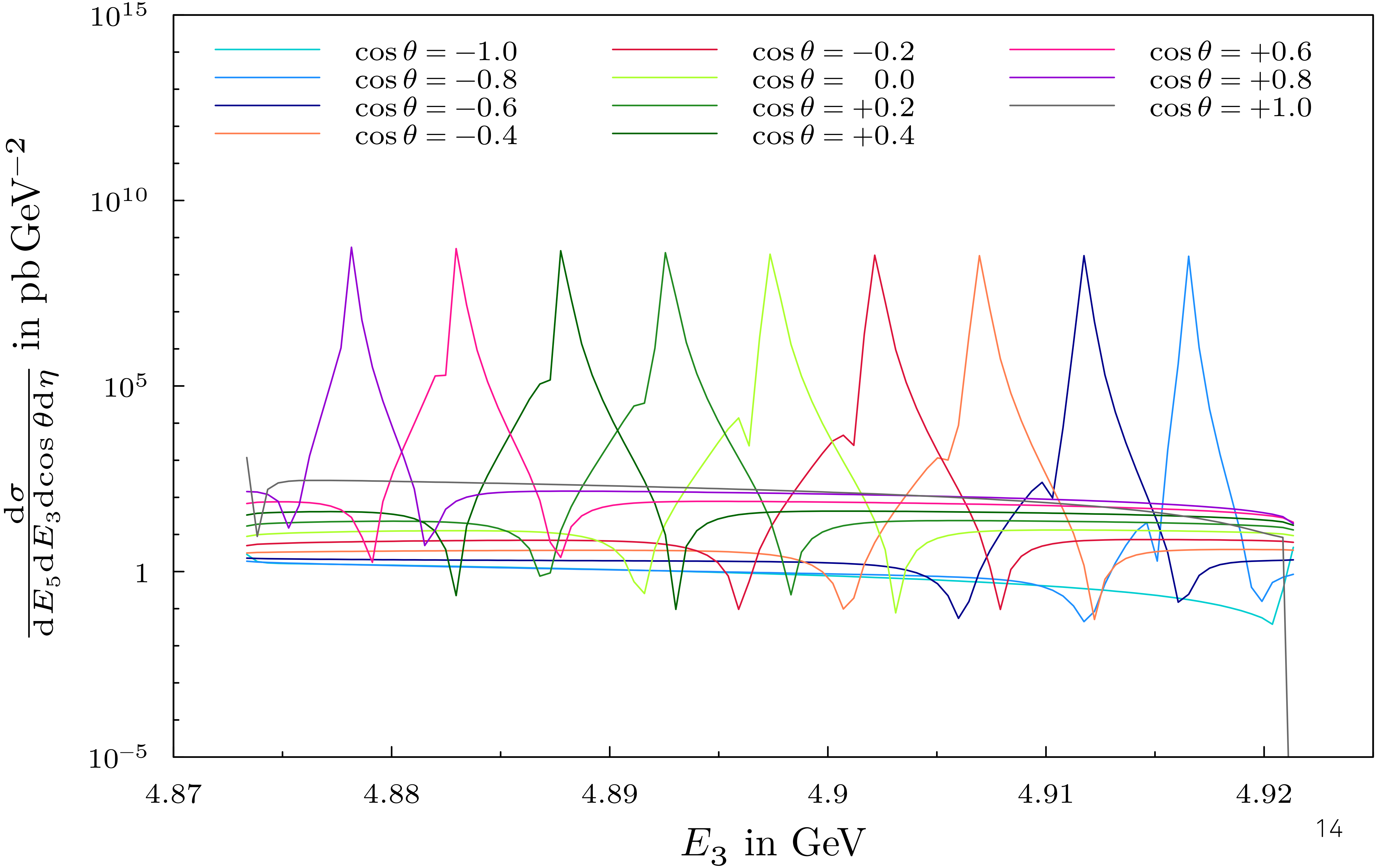


Results

First Approach



Problems



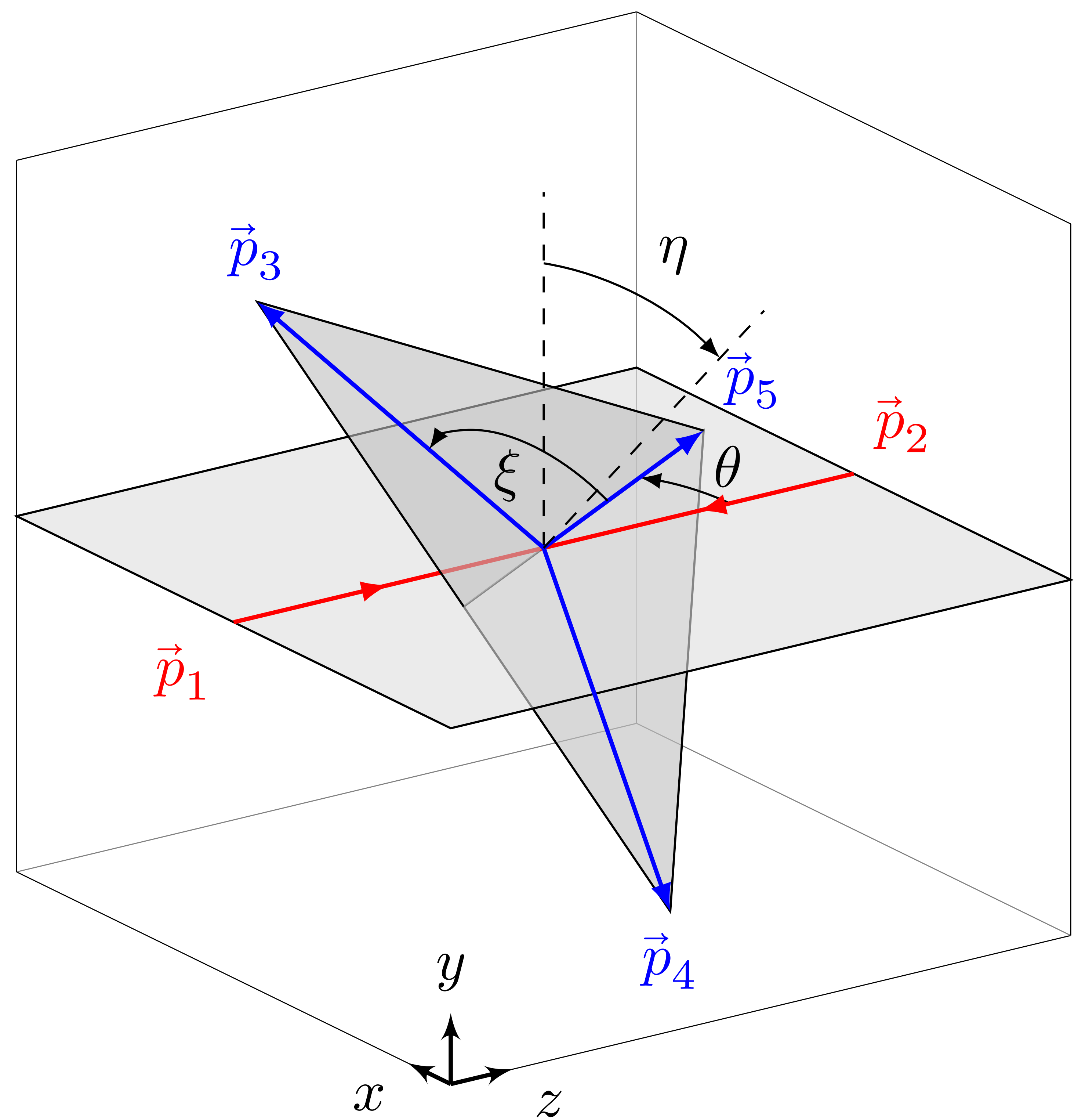
$\cos\theta = -1.0$
$\cos\theta = -0.8$
$\cos\theta = -0.6$
$\cos\theta = -0.4$
$\cos\theta = -0.2$
$\cos\theta = \ \ 0.0$
$\cos\theta = +0.2$
$\cos\theta = +0.4$
$\cos\theta = +0.6$
$\cos\theta = +0.8$
$\cos\theta = +1.0$
10^{15}
10^{10}
10^{5}
1
10^{-5}
4.87
4.88
4.89
4.9
4.91
4.92
$\frac{\mathrm{d}\sigma}{\mathrm{d}E_5\,\mathrm{d}E_3\,\mathrm{d}\cos\theta\,\mathrm{d}\eta}$ in pb GeV^{-2}
E_3 in GeV

Phase Space

Second Approach

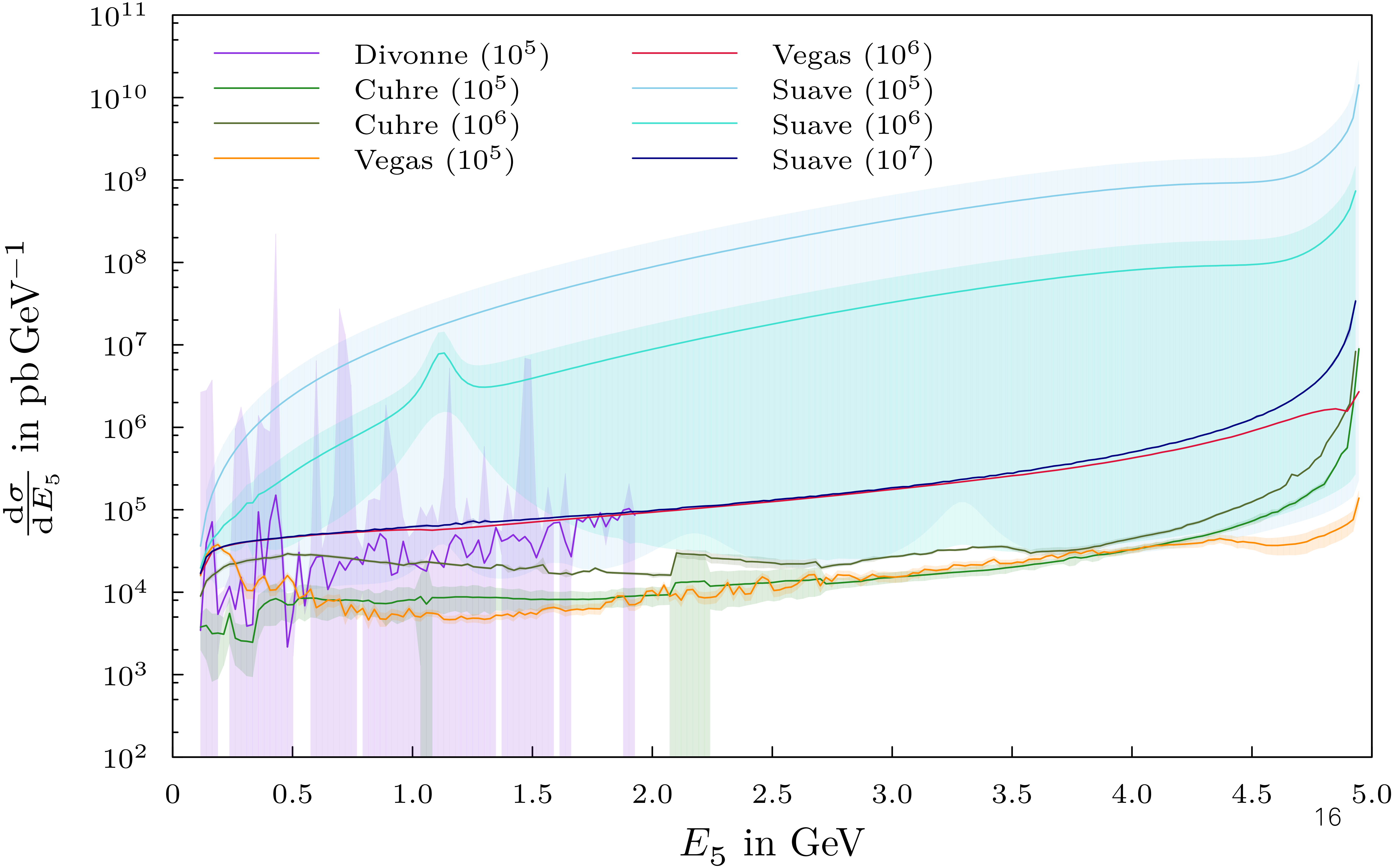
- two energies and two angles
- **better suited for bremsstrahlung**

$$R_3 = \frac{\pi}{4} \int \mathrm{d}E_5 \, \mathrm{d}E_3 \, \mathrm{d}\cos\theta \, \mathrm{d}\eta$$



Results

Second Approach



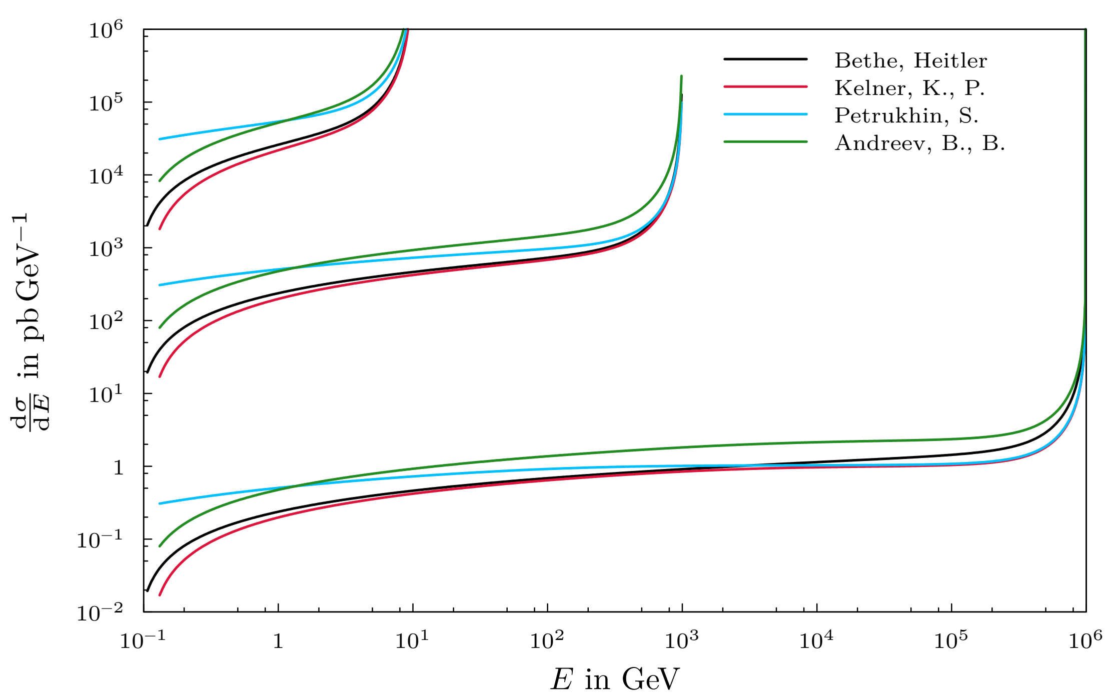
Results

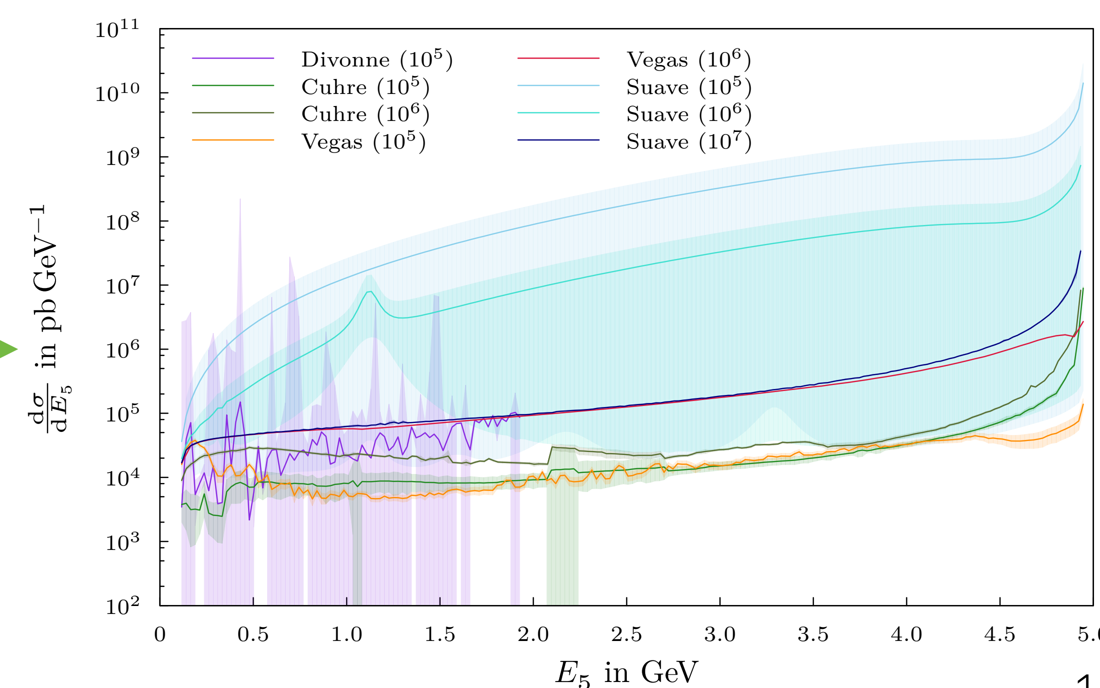
Second Approach

- better than first approach
- similar behavior to existing cross sections

But:

- both calculations in center of mass system
  - **not comparable to existing cross sections**

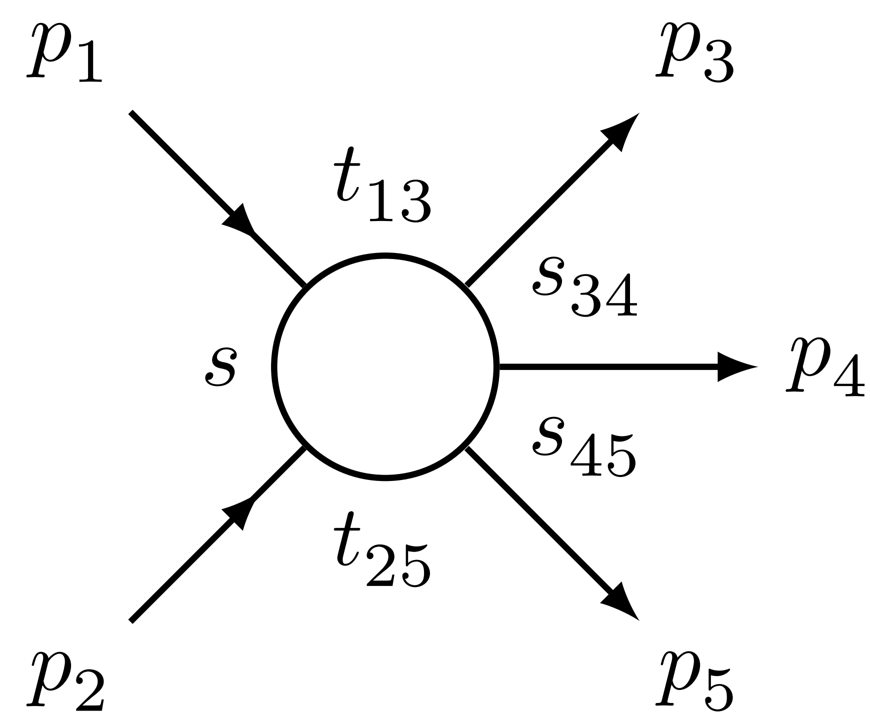




Phase Space

Third Approach

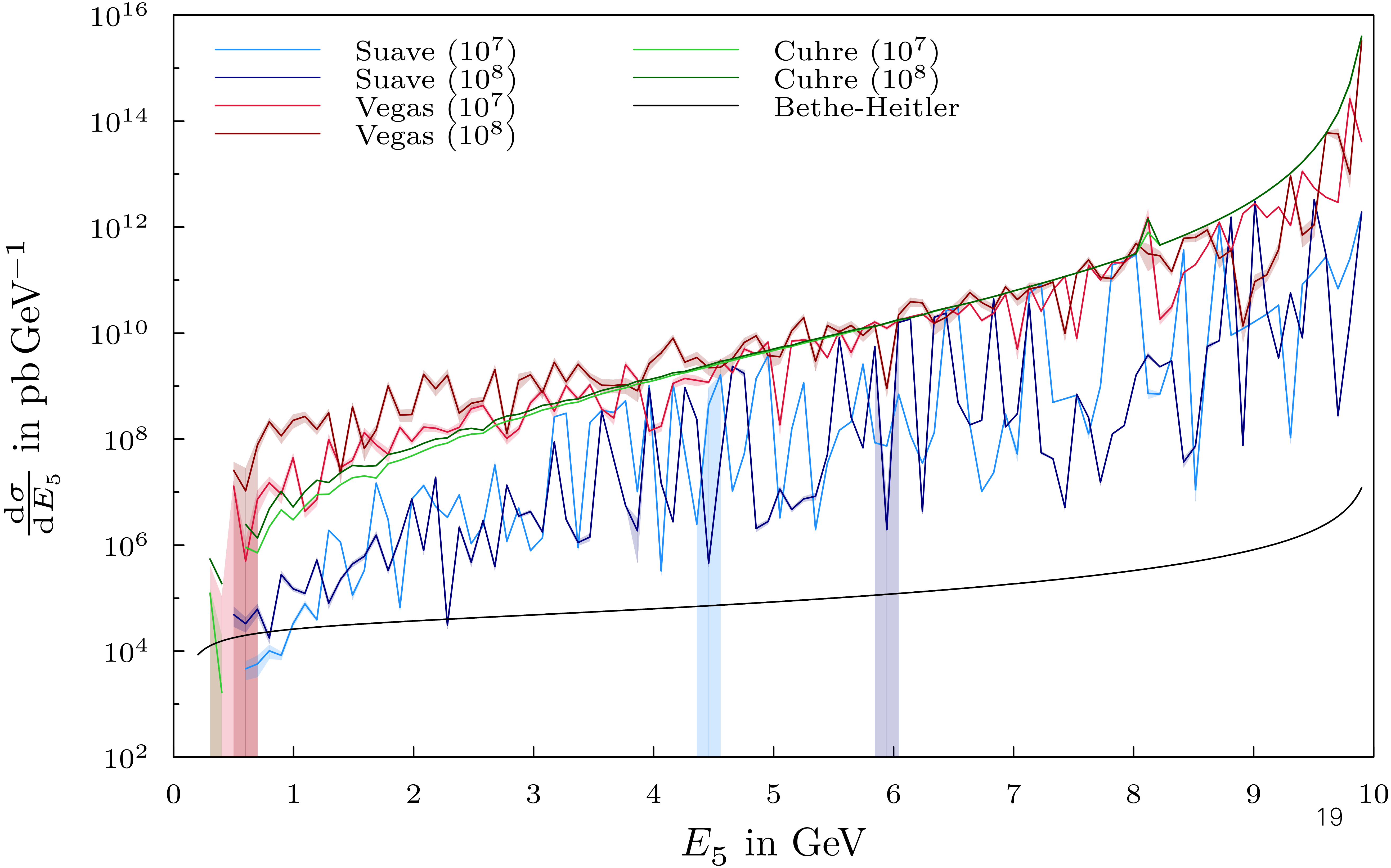
- 4 kinematic invariants
- complicated border functions
- **comparison to existing cross sections possible**



$$R_3 = \frac{\pi}{16\sqrt{\lambda(s, m_1^2, m_2^2)}} \int \mathrm{d}t_{25}\, \mathrm{d}s_{34} \int \mathrm{d}s_{45}\, \mathrm{d}t_{13}\, \frac{1}{\sqrt{-\Delta_4}}$$

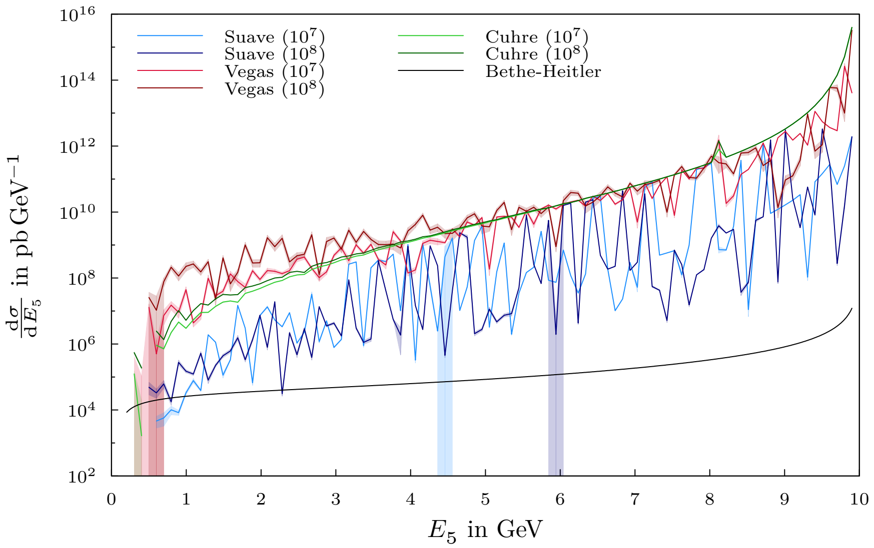
Results

Third Approach



Summary

- need for more precise cross sections
  - systematic errors higher than statistical ones
- new muon-proton-bremsstrahlung cross section
  - **numerical calculation problematic**
  - **instable even for small energies**
  - optimal phase space not found yet



- **further studies only make sense if numerical integration problem is solved**