Computer Tools for Nuclear Physics

Databases of photon- and hadron-induced reactions:

XCOM, SAID, NN-OnLine, PDG Rev. Part. Phys.

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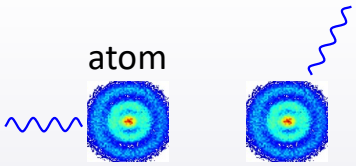
XCOM – introduction

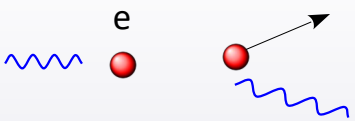
❖ **XCOM** – program for photon + medium processes. Photon ∈ {X, γ}. Absorber ∈ {nucleus/atom, compound, mixture}.
It gives **cross sections** (σ) and **mass attenuation coefficients** (μ_m),
based on model calculations + semi-empirical formulae.

- Photon energies: 1 keV – 100 GeV.
  Target nuclei: Z ≤ 100.

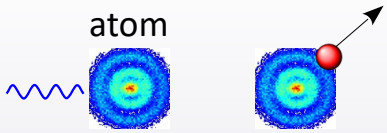
  Considered effects: **Rayleigh scattering**, **Compton scattering**, **photoelectric absorption**, **pair production**
  in the fields of: atomic nucleus and electrons



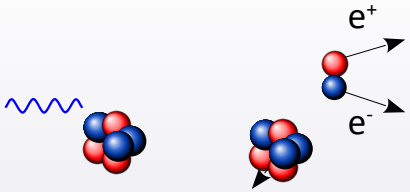
Rayleigh (coherent) **scattering**



Compton (Incoherent) **scattering**



Photoelectric effect (absorption)



Pair (e^+e^-) production

☞ Cross section (σ), mass attenuation coefficient (μ_m), attenuation coefficient (μ) and attenuation length (λ) :

$$\sigma = \mu_m \cdot \frac{M_{mol}}{N_{Av}} \qquad \mu_m \equiv \frac{\mu}{\rho} \qquad \lambda \equiv \frac{1}{n\sigma}$$

where: ρ = density

- XCOM on the web: [**home page**] and [**search form**]

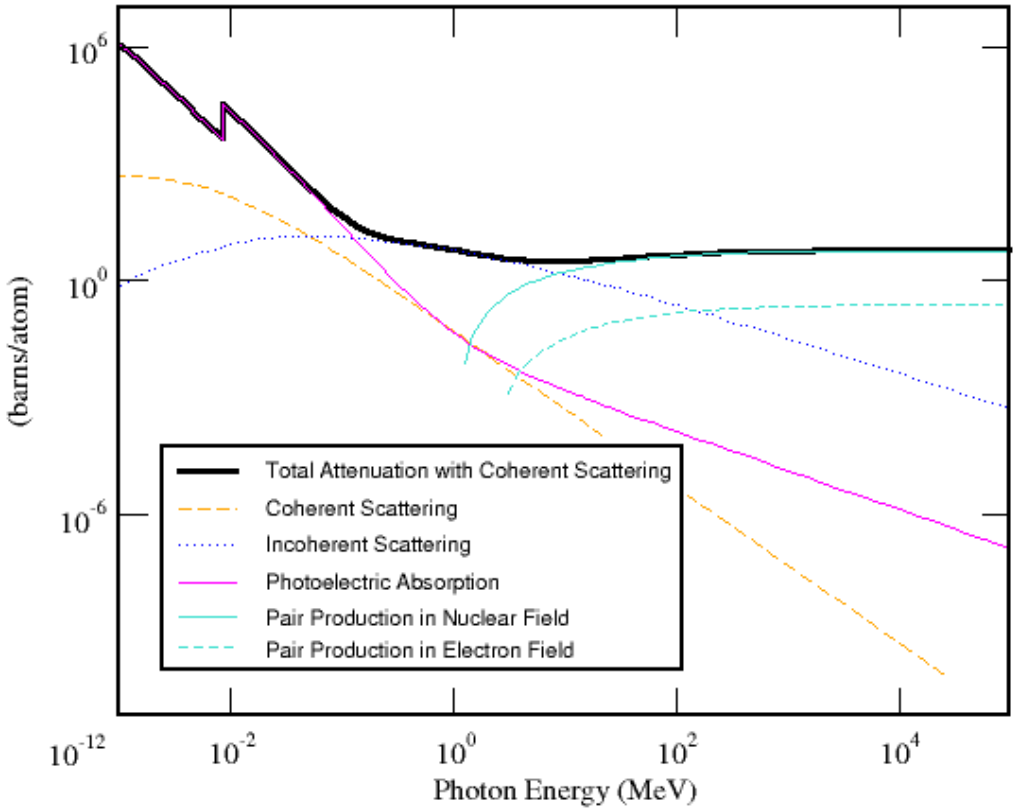
- The fortran code for Dos and Unix systems can be also downloaded [**here**].
  Linux/Unix systems: first compile the code (`gfortran XCOM.f -o XCOM.exe`), then run.
  Windows: run the executable.

XCOM – introduction

- Open the **XCOM** search form.
  Select the medium type: **Element** (photon + A), **Compound** (photon + molecule), **Mixture** (of molecules).
  Let's try Element . Click [**Submit Information**].

- Select an atom/nucleus → e.g. Ni
- Select units → let's try barns/atom
- Graph options → let's choose Coherent & Incoherent Scattering + Photoelectric Absorption + Pair Producton in Nuclear and Electron Field.
  If you want all together, click [**Total**] .
- Energy Range: → let's choose widely: [0.001 – 100000] MeV.

You'll get this [plot] and [table] :



Edge	(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
		Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
	MeV	barns/atom	barns/atom	barns/atom	barns/atom	barns/atom	barns/atom	barns/atom
	1.000E-03	4.924E+02	7.613E-01	9.600E+05	0.000E+00	0.000E+00	9.605E+05	9.600E+05
	1.004E-03	4.921E+02	7.661E-01	9.500E+05	0.000E+00	0.000E+00	9.505E+05	9.500E+05
	1.008E-03	4.919E+02	7.709E-01	9.406E+05	0.000E+00	0.000E+00	9.411E+05	9.406E+05
28 L_1	1.008E-03	4.919E+02	7.709E-01	1.071E+06	0.000E+00	0.000E+00	1.071E+06	1.071E+06
	1.500E-03	4.640E+02	1.355E+00	4.122E+05	0.000E+00	0.000E+00	4.127E+05	4.122E+05
	2.000E-03	4.334E+02	1.910E+00	1.992E+05	0.000E+00	0.000E+00	1.996E+05	1.992E+05

You can download the data (txt), specifying the effect(s).
You should get:

```
Photon     Coherent Incoher. Photoel. Nuclear  Electron
Energy     Scatter. Scatter. Absorb.  Pr. Prd. Pr. Prd.

1.000E-03 4.924E+02 7.613E-01 9.600E+05 0.000E+00 0.000E+00
1.004E-03 4.921E+02 7.661E-01 9.500E+05 0.000E+00 0.000E+00
1.008E-03 4.919E+02 7.709E-01 9.406E+05 0.000E+00 0.000E+00
1.008E-03 4.919E+02 7.709E-01 1.071E+06 0.000E+00 0.000E+00
```

SAID – introduction

❖ **SAID** (**S**cattering **A**nalysis **I**nteractive **D**ialin) – database of experimental and model parameters on specific processes involving hadrons @ low and intermediate energies:

$pp \to pp$,	$np \to np$			(NN elastic scattering)
$\pi^{\pm} p \to \pi^{\pm} p$,	$\pi^- p \to \pi^0 n$			(pion-induced elastic scattering)
$\pi^{\pm} p \to \pi^{\pm} \pi^0 p$,	$\pi^{\pm} p \to \pi^+ \pi^- n$			($\pi\pi$ production)
$K^+ p \to K^+ p$,	$K^+ d \to K^+ d$,	$K^+ d \to K^+ p n$,	$K^0_L p \to K^+ n$	(K-induced elastic, breakup, charge-exchange)
$\gamma N \to \pi^0 N$,	$\gamma p \to \pi^+ n$,	$\gamma n \to \pi^- p$,	$\pi^- p \to \gamma N$	(photoproduction of pions & inverse)
$\gamma N \to K^+ \Lambda$,	$\to K^+ \Sigma^0$,	$\to K^0 \Sigma^+$		(photoproduction of kaons and hyperons)
$\gamma N \to \eta N$,	$\to \eta' N$			(photoproduction of η and η' mesons)
$e^- N \to e' N \pi^0$,	$e^- p \to e' n \pi^+$,	$e^- n \to e' p \pi^-$		(electroproduction of pions)
$\pi^{\pm} d \to \pi^{\pm} d$,	$\pi^+ d \to p p$			(πd elastic scattering and pp production)

- You can extract differential cross section: $d\sigma/d\Omega = f(\theta)$ at fixed T_{Beam} or $d\sigma/d\Omega = f(T_{Beam})$ at fixed θ.
  Sometimes also integrated cross section (σ). The unit is mb/sr (or mb).
  Often many scattering-specific observables are available. They will not be covered in this tutorial.
- The data are experimental and theoretical. For model description: **PWA** (**P**lane-**W**ave **A**nalysis).
- You get: plot, tabularized printout, reference list.
- **SAID web interface**: [**here**]

  Talk on SAID: [**here**]
- Platform started in 1980s, now offers several hundred thousands data points.

SAID – how to plot and print the data

- Open the **SAID** web interface.

- Menue "**Partial-Wave Analyses at GW**" :
  → select the reaction family you need (e.g. Nucleon-Nucleon).

- Submenue:
  Analysis Options (most basic options)
  Data Base = Listing of references
  Observables = Plots and data printout [**click it**]

- "**Give Predictions for Observables**"
  → We focus on exp data itself, so choose any model.

- You will always see default suggestions.
  If you just start training, start from these defaults.

- "Choose a Reaction type" → e.g. PP
  "Isospin Components (0 and 1)" → (applicable to NP only).
  If not clicked, you mean total σ.

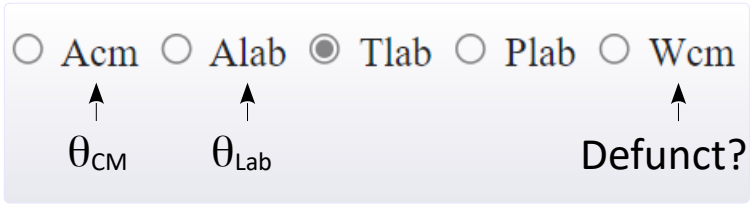
- "Choose Observable … Enter one of the above observable types: "
  → We'll first search for $d\sigma/d\Omega$, so type **DSG**.

- "Enter independent variable" → $d\sigma/d\Omega$ as a function of this variable.
  Let's try Acm (= θ_{CM})
  Below set range [0, 10, 180] deg

- "Enter fixed variable" → $d\sigma/d\Omega$ at fixed this variable.
  Let's try Tlab.
  Below set range [200, 210] MeV.

- Then click [**Start**].

Partial-Wave Analyses at GW
[See Instructions]
Pion-Nucleon
Pi-Pi-N
Kaon(+)-Nucleon
Nucleon-Nucleon
Pion Photoproduction
Pion Electroproduction
Kaon Photoproduction
Eta Photoproduction
Eta-Prime Photoproduction
Pion-Deuteron (elastic)
Pion-Deuteron to Proton+Proton



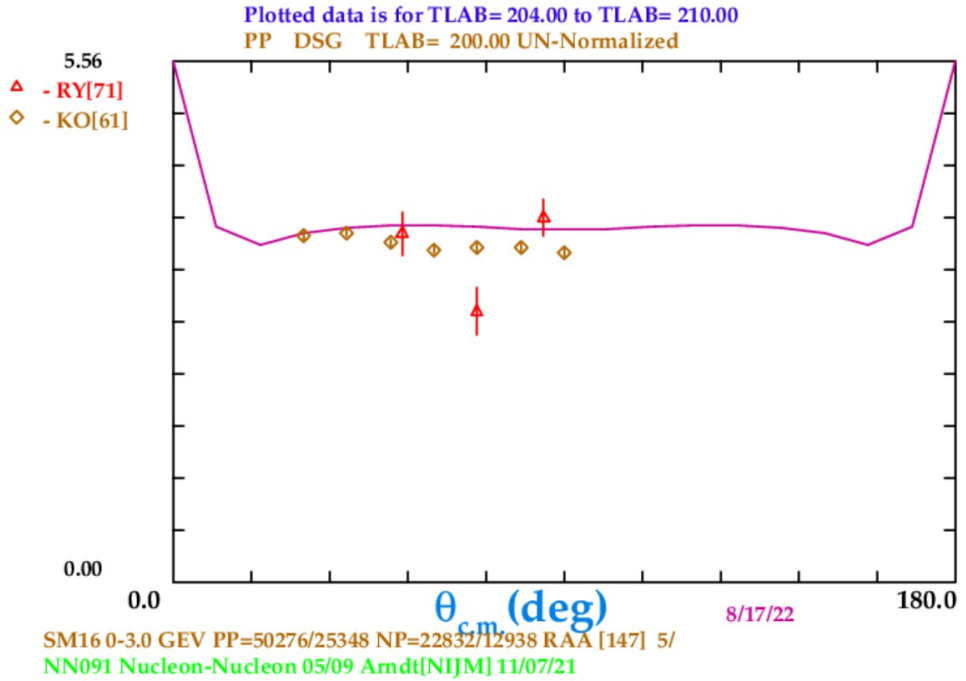
SAID – how to plot and print the data

☞ You should obtain such a plot: ⟶

- **Curve**: model predictions (based on PWA).
- **Points**: we see 2 series of data points. Why?

- Below the plot you can find the data printout:
  - model prediction of $d\sigma/d\Omega$ [mb/sr] = f(θ_{CM} [°])
  - experimental data sets

- We see that 2 datasets were found within our specified energy range (⇒ 2 series of points).
  You may return to prev. page and limit the scope.



Model predictions ☞

```
SM16 0-3.0 GEV PP=50276/25348 NP=22832/12938 RAA (147)  5/03/07
    PP    DSG  at TLAB=  200.00     8/17/22
    ACM   Obs,Err
   A(cm)      DSG(cm)        Err      A(lab)     DSG(lab)
    0.000  0.5558E+01  0.0000E+00     0.00  0.2460E+02
   10.000  0.3796E+01  0.0000E+00     4.75  0.1672E+02
   20.000  0.3604E+01  0.0000E+00     9.52  0.1564E+02
  ...
```

```
T=  204.000 Nd=   3  RY(71)   PPA   RYAN, PRD3, 1(71)        RsF= 1.000
     52.66  0.37200E+01  0.23000E+00
     69.87  0.28900E+01  0.25000E+00
     85.30  0.38900E+01  0.19000E+00
T=  210.000 Nd=   7  KO(61)   ROCH  KONRADI, THESIS(61)      RsF= 1.000
     30.00  0.37000E+01  0.40000E-01
     40.00  0.37300E+01  0.40000E-01
 ...
```

☞ **Experimental data**

SAID – integrated cross section

- Let's hunt for **integrated cross section** (σ) of: **elastic scattering**, **reaction** ("**inelastic**") and **total** (elastic + reaction)

- Open the **SAID** web interface.
  Menue "**Partial-Wave Analyses at GW**" → select again Nucleon-Nucleon.
  Submenue "**Analysis options**" → select "Observables"

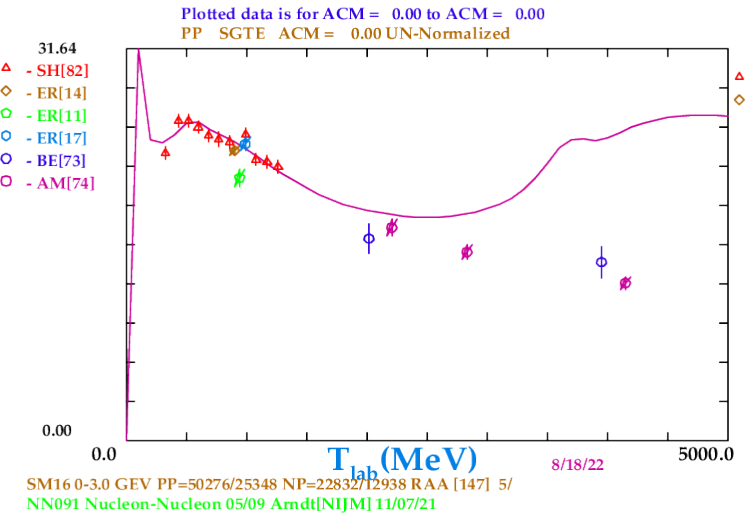
- "Choose a Reaction type" → select PP
  "Isospin Components (0 and 1)" → don't click

- "Choose Observable … Enter one of the above observable types: "
  → for **elastic scattering** type **SGTE**. → For **reaction** type **SGTR**. → for **Total** (elastic + inelastic) type **SGT**.

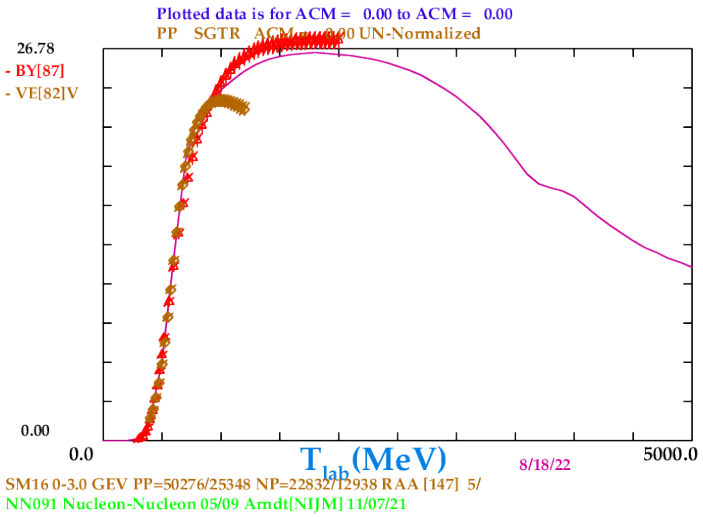
- "Enter independent variable" → select Tlab. Below, set range [0, 100, 5000] MeV.

- "Enter fixed variable" → select Acm, and value to 0. Also, set range to [0, 0].

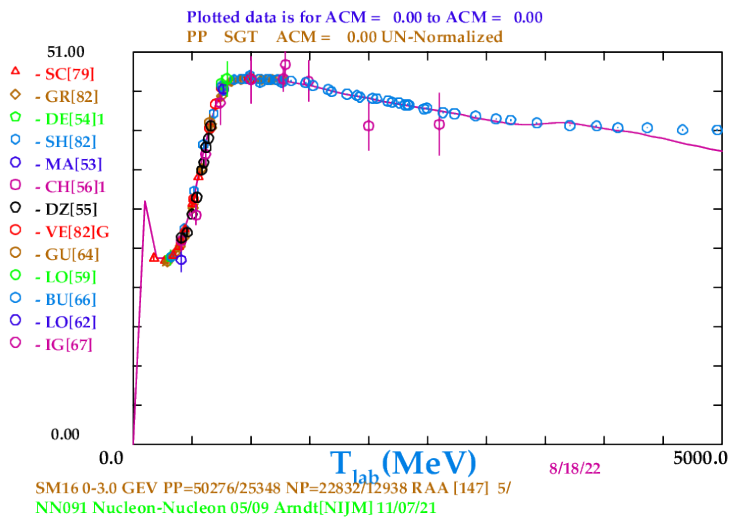
- Then click [**Start**].



σ of pp elastic scattering as f(T_{Lab})



σ of pp reactions as f(T_{Lab})



σ of pp total as f(T_{Lab})

NN-OnLine : introduction

❖ **NN-OnLine** – database of experimental and model parameters on specific processes involving hadrons
@ low and intermediate energies $T_{Beam} \sim$ 1 MeV – few GeV .

$pp \to pp$, $np \to np$	(NN: $d\sigma/d\Omega$ of elastic scattering and σ of total interaction).
Λp , $\Sigma^+ p$, $\Sigma^- p$, $\Xi^0 p$, $\Xi^- p$	(YN: elastic scattering and reactions)

For **NN elastic scattering** you can get **plots & printout** on **exp. differential cross section**, $d\sigma/d\Omega = f(\theta)$ at fixed T_{beam} .

For **NN**, and **YN** (hyperon $Y \in [\Lambda, \Sigma, \Xi]$) you can get **exp. integrated cross sections** (σ) – only as tabularized data.
Many other scattering-specific observables are available. They are not covered in this tutorial.

Many variants of model description. This topic is also not covered here.

- **NN-OnLine web interface**: [**here**] .

  Papers on theoretical models describing the exp. data: [**here**]

- Platform was launched in 1994.

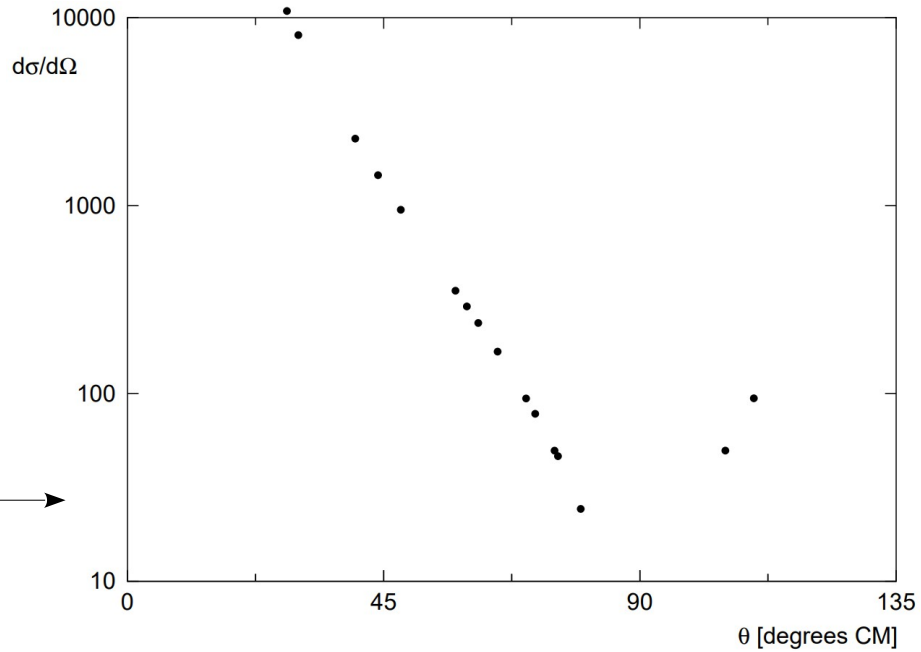
NN OnLine – NN elastic scattering dσ/dΩ

- Open the **NN-OnLine** web interface.
- From left menue click "**NN interaction**" :
  → right to "**Experimental NN scattering data**" click "**Browse the NN database**"
- Reaction → let's try "proton-proton".
- Energy of the incoming particle: → try widely, $T_{Lab} \in [0.001 – 5000]$ MeV
- Observable: → for **differential cross section** ($d\sigma/d\Omega = f(\theta)$ at fixed T_{beam}) choose **DSG**.
- Then click [**Start**] . You'll get a listing of data sets at increasing T_{Lab} range, with entries like this:

0.29976 - 0.40679 MeV

DO97 H. Dombrowski *et al.*, Nucl. Phys. **A619** (1997), 97-118 *(Muenster)*
14 DSG data at 90.0 degrees (*)

- Let's scroll down to "0.35009 MeV" ,
  as it contains many points in wide range of θ angles.
  Click [**19 DSG**].
- First, click [**Show the data**].
  You'll get the table of [θ, dσ/dΩ] points + reference.
- Get back and click [**Plot the data**].
  You can choose the X axis to be θ_{CM} or cos (θ_{CM}) .
  Also, formats: PostScript, PDF (better resolution) and png.
  Click [**Start**] and you should get this plot: →



The unit of dσ/dΩ is mb/sr .

NN OnLine – integrated total cross sections

❖ Open **NN-OnLine**. From menue click "**NN interaction**" :
→ right to "**Experimental NN scattering data**" click "**Browse the NN database**"

- Reaction → let's try "neutron-proton".

  Energy of the incoming particle: → try widely, $T_{Lab} \in [0.001 – 5000]$ MeV

  Observable: → for **total integrated cross section** (elastic+inelastic; σ_{TOT}) choose **SGT**.

  Then click [**Start**] .
  You'll get a listing of data sets
  at increasing T_{Lab} range, with entries like this:

  0.00197 - 0.143 MeV

  KO90 L. Koester *et al.*, Z. Phys. A **337** (1990), 341-348
  2 SGT data

  Let's scroll down to [0.5 – 24.6] MeV,
  as it contains many points. Click [**425 SGT**] and then [**Show the data**]. You'll get a list of $\sigma = f(T_{Lab})$ [mb].

- Let's explore the **YN interactions**. From menue click "**YN interaction**"
  → right to "**Data**" click "**The database of YN scattering data**".

  Out of 5 variants {Λp , Σ^+p , Σ^-p , Ξ^0p , Ξ^-p} we should pick the one we want. Let's try Λp (click "Λp scattering").

  The Λp interaction can be: elastic scattering (Λp → Λp) or reactions (Λp → Σ^0 p, Λp → Σ^+n). Click e.g. Λp → Σ^0 p.

  Under "Total cross section" you will find the table of [p, σ] points + references (clickable):

momentum range (MeV/c)	number of events	SGT (mb)	reference
639 - 1000	3	8.5 +/- 4.9	AL61
640 - 800		8.0 +/- 4.0	HA77
650 - 700		2.8 +/- 2.0	KA71
660 - 4000	11	1.5 +/- 0.5	CH70
700 - 800		7.5 +/- 2.5	KA71

PDG Review of Particle Physics – Introduction

❖ **PDG** (**P**article **D**ata **G**roup) Review of Particle Physics
is the basic reference for properties of particles (fundamental and hadrons) like: mass, lifetime etc.

It contains **cross sections** = *f* (energy / momentum) for "**total elastic**" and "**total collision**" processes up to **very high energies** (through LHC and beyond, from cosmic particles).

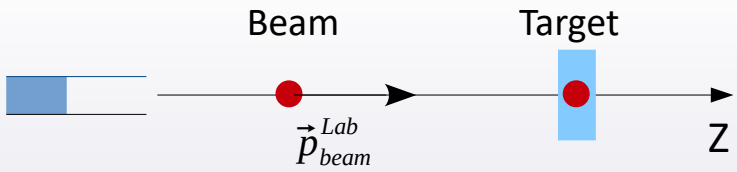
Collisions enlisted:

pp, np, pd, $\bar{p}$p, $\bar{n}$p, $\bar{p}$d
$\pi^{\pm}$p, $\pi^{\pm}$d, Σ^{-}p
$K^{\pm}$p, $K^{\pm}$n, $K^{\pm}$d
γp, γd, $\gamma\gamma$

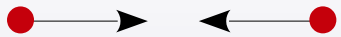
The current edition is always at **pdg.lbl.gov**. But let's go the previous one, [**here**] .
Click [Reviews, Tables, Plots] and further [Kinematics, Cross-Section Formulae, and Plots].
On the [Plots of cross sections and related quantities (rev.)] click [interactive version] .

Here, find the pair of particles of your interest. You will get σ = f(energy/momentum) as:
[PDF] = static plots in pdf or [Data] = tabularized data points.

Quantities and units: p_{Lab} [GeV/c] of beam in stationary target exp. $\sqrt{s}$ [GeV] = available energy in the CM frame.



Lab frame in Fixed target experiment



CM frame

Translation *p* ↔ √s

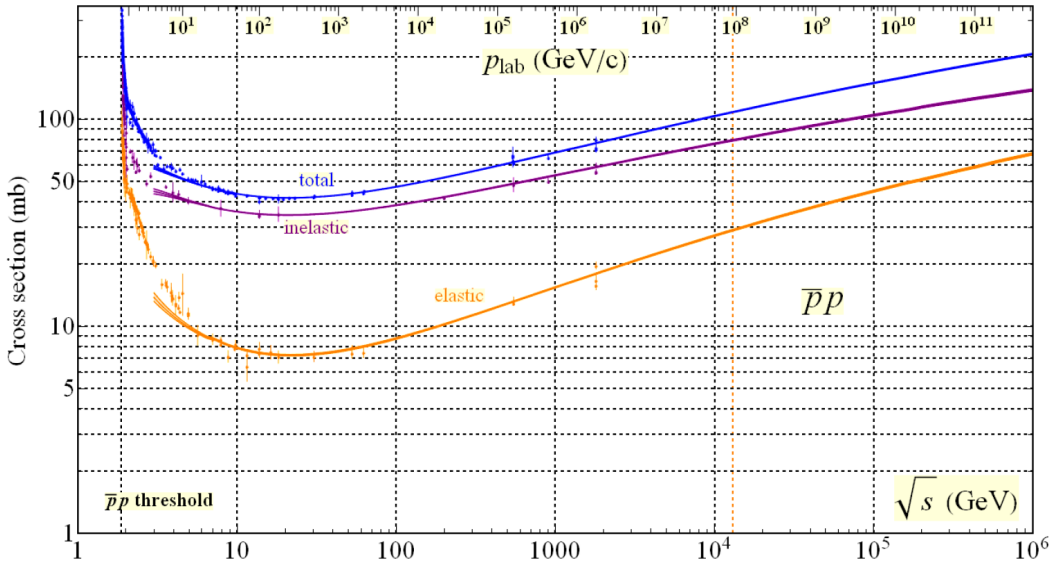
$$E_{beam}^{Lab} = \sqrt{p_{Lab}^2 + m_{beam}^2}$$

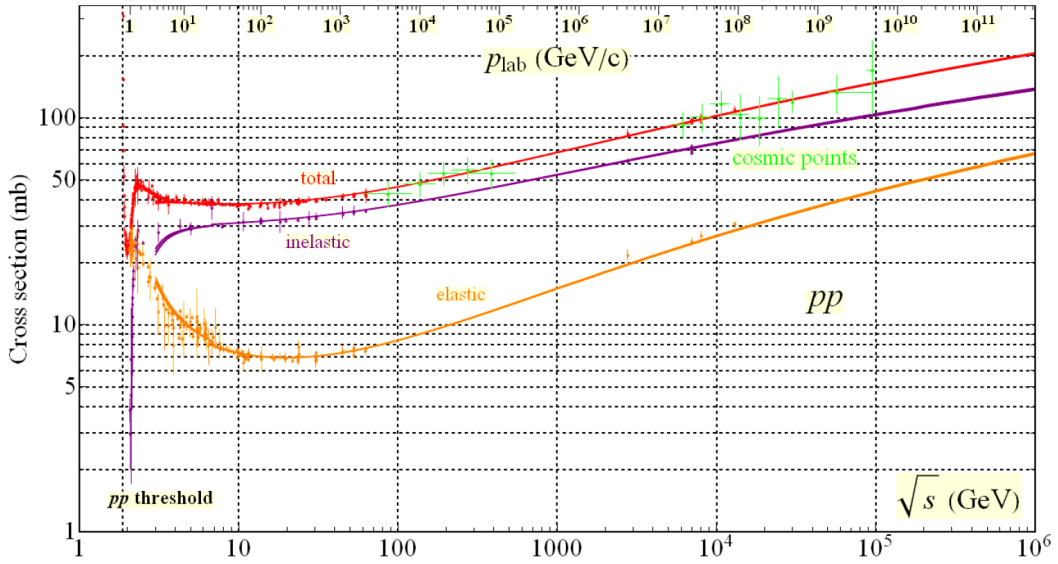
$$T_{beam}^{Lab} = E_{beam}^{Lab} - m_{Beam}$$

$$\sqrt{s^{CM}} = \sqrt{2\,m_{beam}\left(2\,m_{beam} + T_{beam}^{Lab}\right)}$$

PDG Review of Particle Physics – Exemplary output

- Let's take the pp and $\bar{p}p$ cross sections and check the pdf plots and data:






```
FILE_NAME
REACTION
BEAM_MASS TARGET_MASS THRESHOLD FINAL_STATE_MULTIPLICITY
NUMBER_OF_DATA_POINTS
POINT_NUMBER PLAB(GEV/C) PLAB_MIN PLAB_MAX SIG(MB) STA_ERR+ STA_ERR- SY_ER+(PCT) SY_ER-(PCT) REFERENCE FLAG
 FORMAT(I5,1X,4F11.5,2F8.4,1X,2F6.1,A)
-------------------------------------------------------------------------------------------------------
PBARP_TOTAL.DAT
PBAR P --> X
0.938270    0.938270      0.            0
444
1    0.18100    0.17300    0.18900    339.40     30.600  30.600     0.0  0.0  BRUCKNER 85B     PL 158B, 180
2    0.18100    0.18100    0.18100    339.40     30.600  30.600     0.0  0.0  BRUCKNER 91B     ZP A339, 367
3    0.21900    0.21900    0.21900    292.10     23.600  23.600     0.0  0.0  BRUCKNER 91B     ZP A339, 367
4    0.21900    0.21500    0.22300    292.10     23.600  23.600     0.0  0.0  BRUCKNER 85B     PL 158B, 180
5    0.22190    0.22190    0.22190    317.71     3.0300  3.0300     0.9  0.9  BUGG 87          PL 194B, 563
6    0.22960    0.22960    0.22960    304.67     1.6300  1.6300     0.9  0.9  BUGG 87          PL 194B, 563
```