The Interaction Region of High Energy Protons

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QCD at Cosmic Energies Chalkida, Greece

based on paper w. I. Dremin, submitted to Phys. Lett.
http://arxiv.org/pdf/1604.03469v2.pdf

What have we learned so far at LHC?
What will we learn from new data, including so far unpublished measurements at 7,8,13 TeV?

Inward Bound

http://4.bp.blogspot.com/-PkEt-k3gwrg/VKb1ZL6B5BI/AAAAAAAAais/o2F37Afrj3s/s1600/qingpu+statue.jpg

Qingpu Oriental Land Garden, Eastern China

Early History*

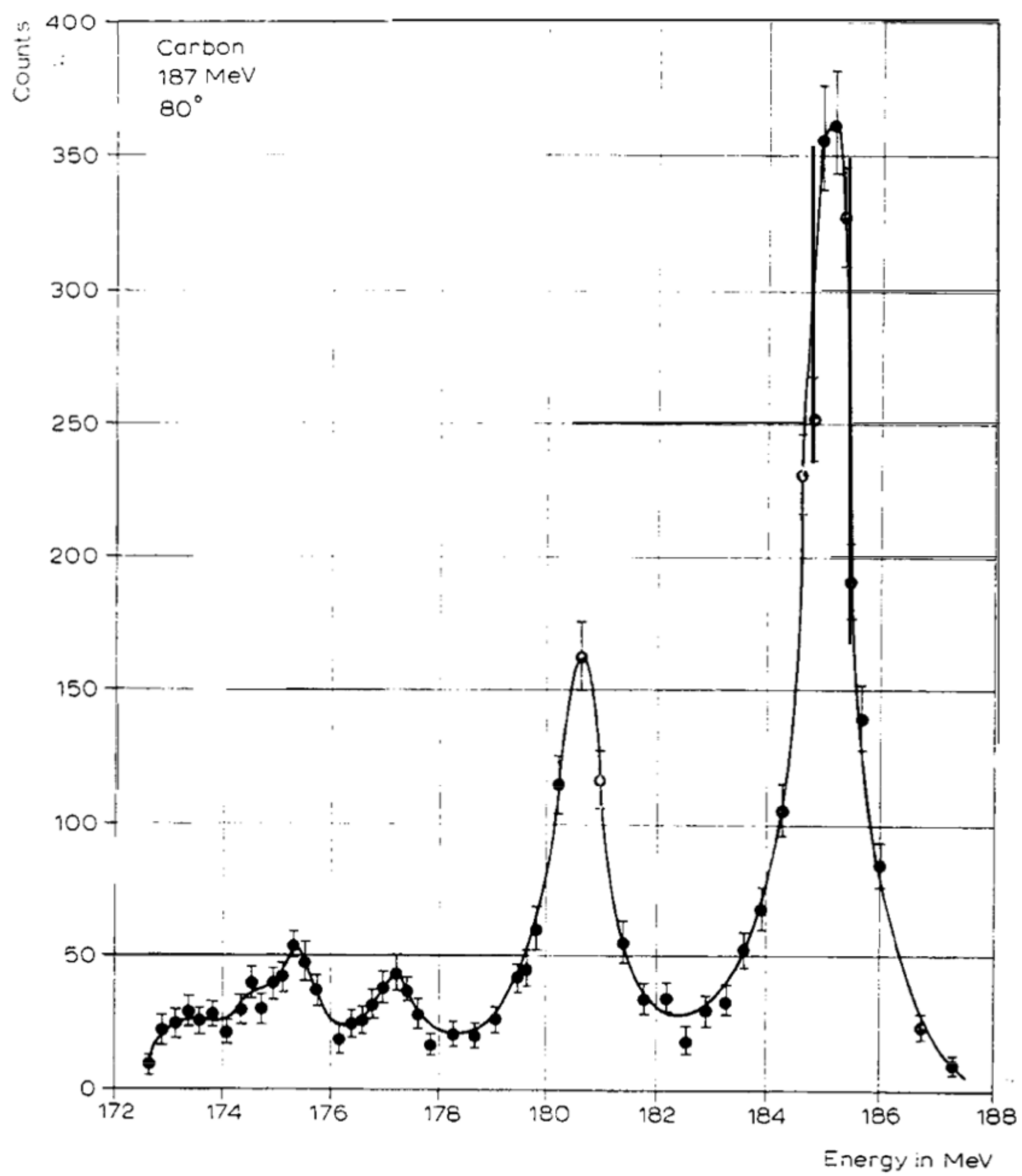
- post WWI: Rutherford and Chadwick continue alpha scattering experiments with light targets- ie Lithium
- find a “region of anomalous interaction”
- in 1929 annual Royal Society lecture Rutherford proposes continuing to higher energies w. artificial accelerators

*see B. Cathcart “The Fly in The Cathedral”

Fixed Target Techniques(1)

"The electron scattering method"

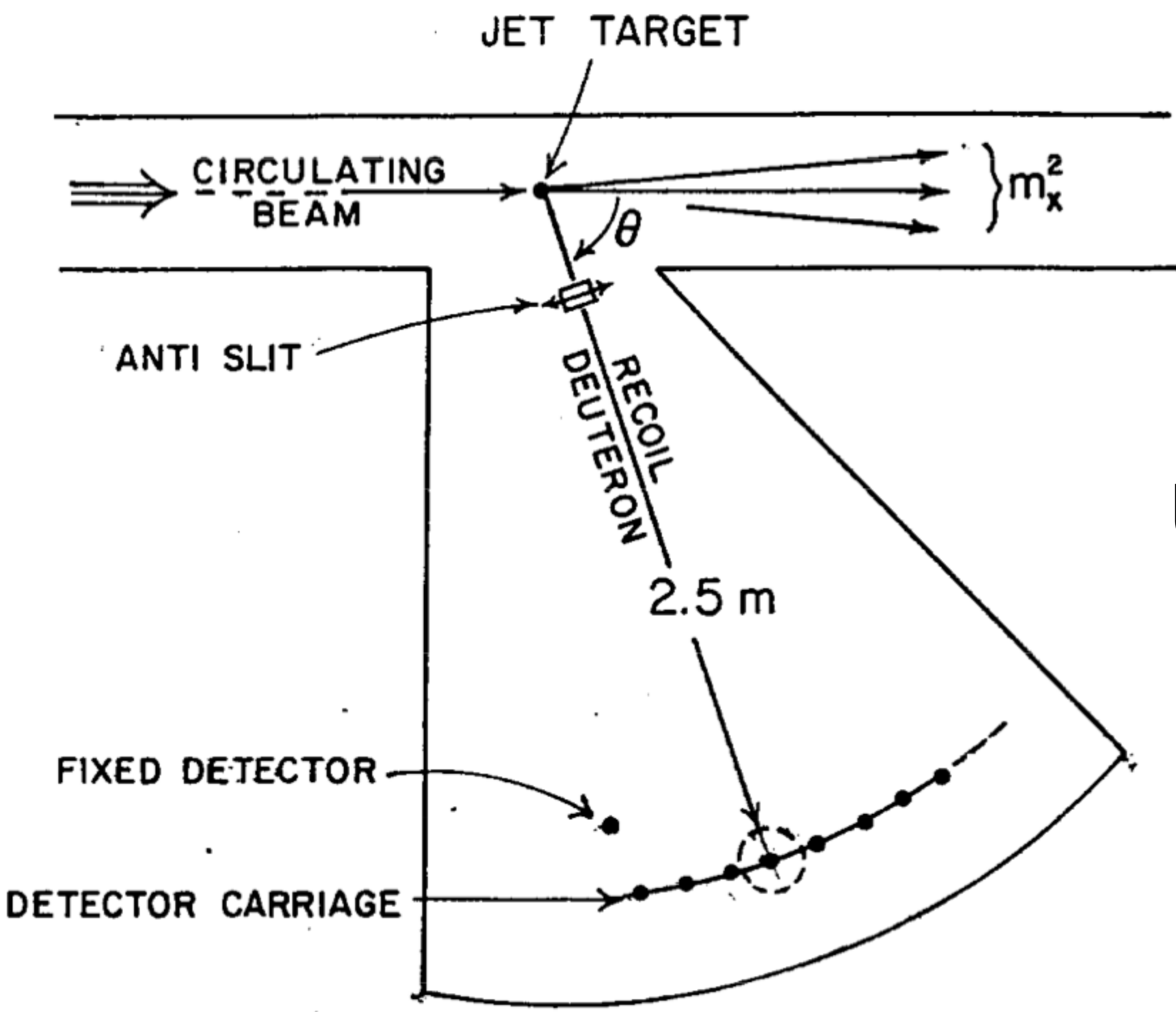
e+N->e'+X



excellent momentum resolution
needed to
resolve elastic part

Complementary Technique: recoil method

h+p(at rest)->X+p(recoil)



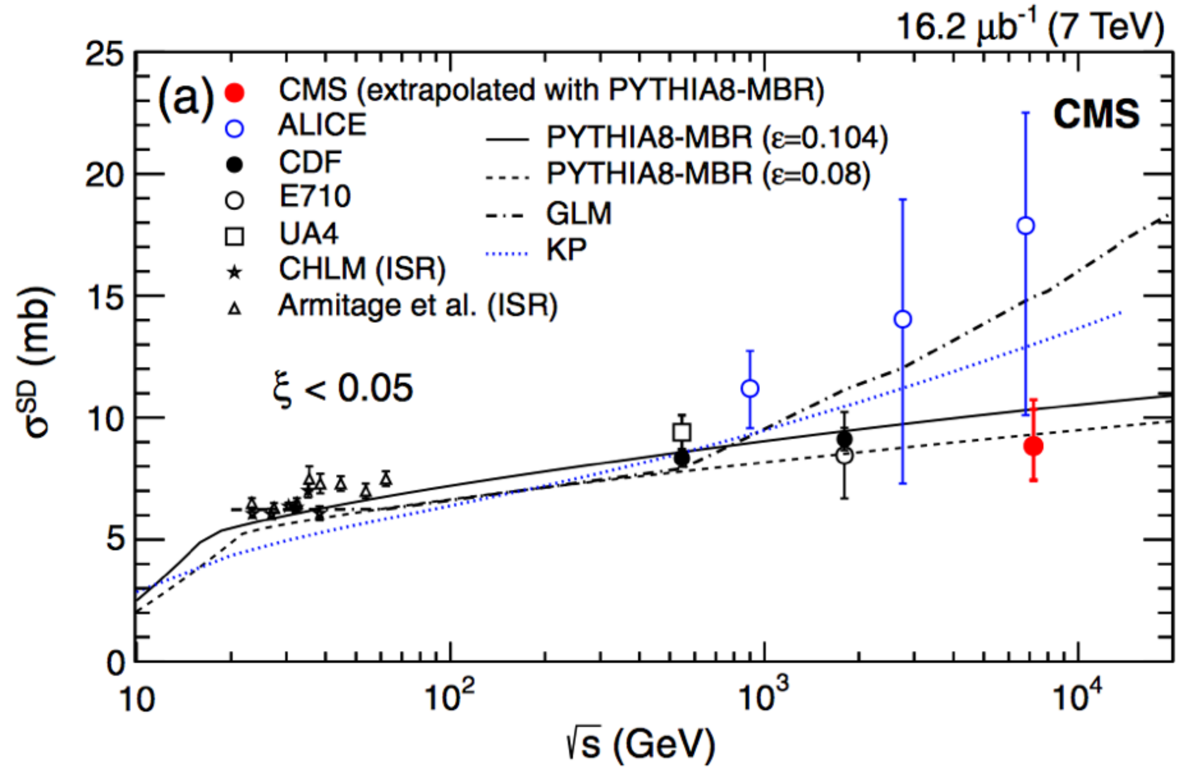
USA-USSR Collaboration

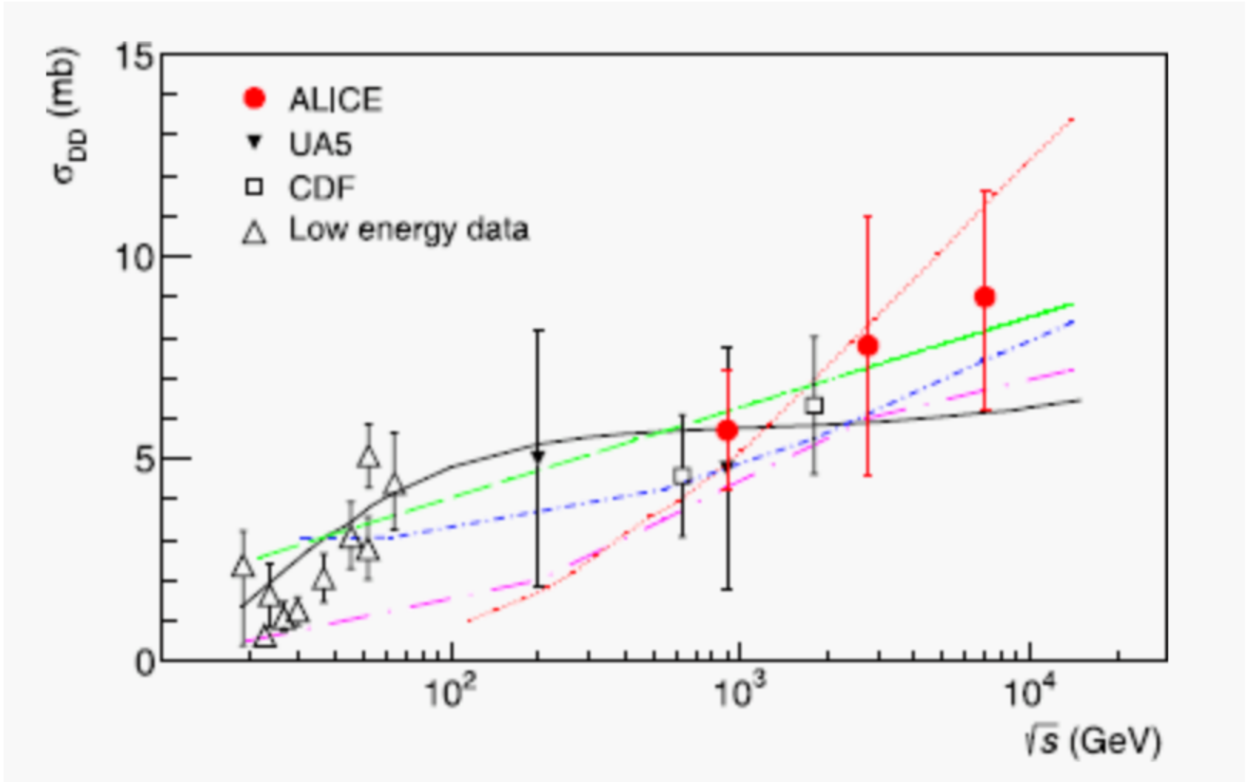
these techniques translated well to elastic scattering at high energy colliders

eg. high precision of 7 TeV TOTEM

$$\sigma_{el}/\sigma_{tot} = 0.257 \pm 0.005$$

but picture less clear in related inelastic diffraction



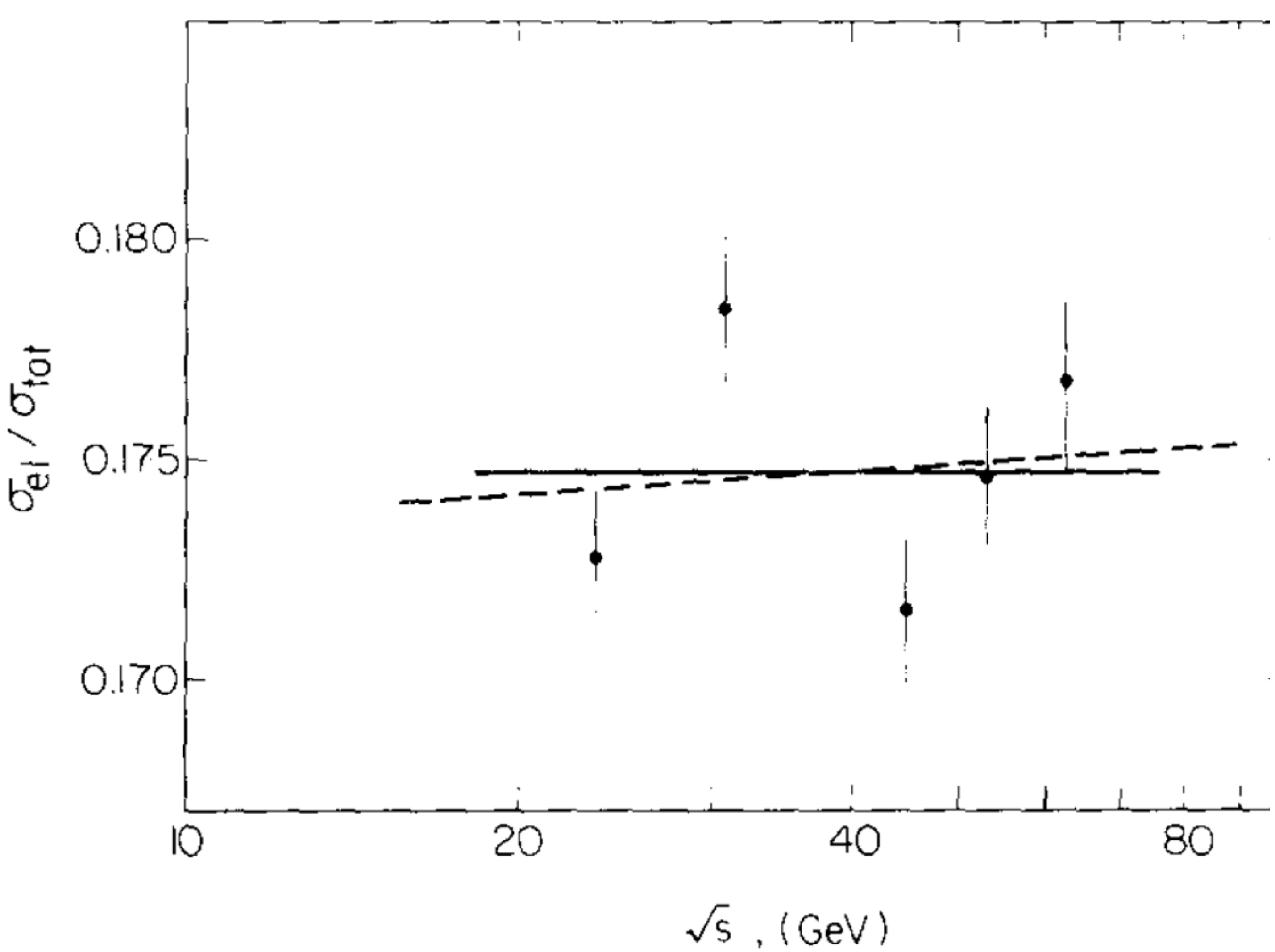


in this talk emphasize what we can learn from high precision elastic data about proton profile

more inelastic diffraction data could help

1980 Review by Amaldi and Schubert

U. Amaldi, K. R. Schubert / Review of all ISR data



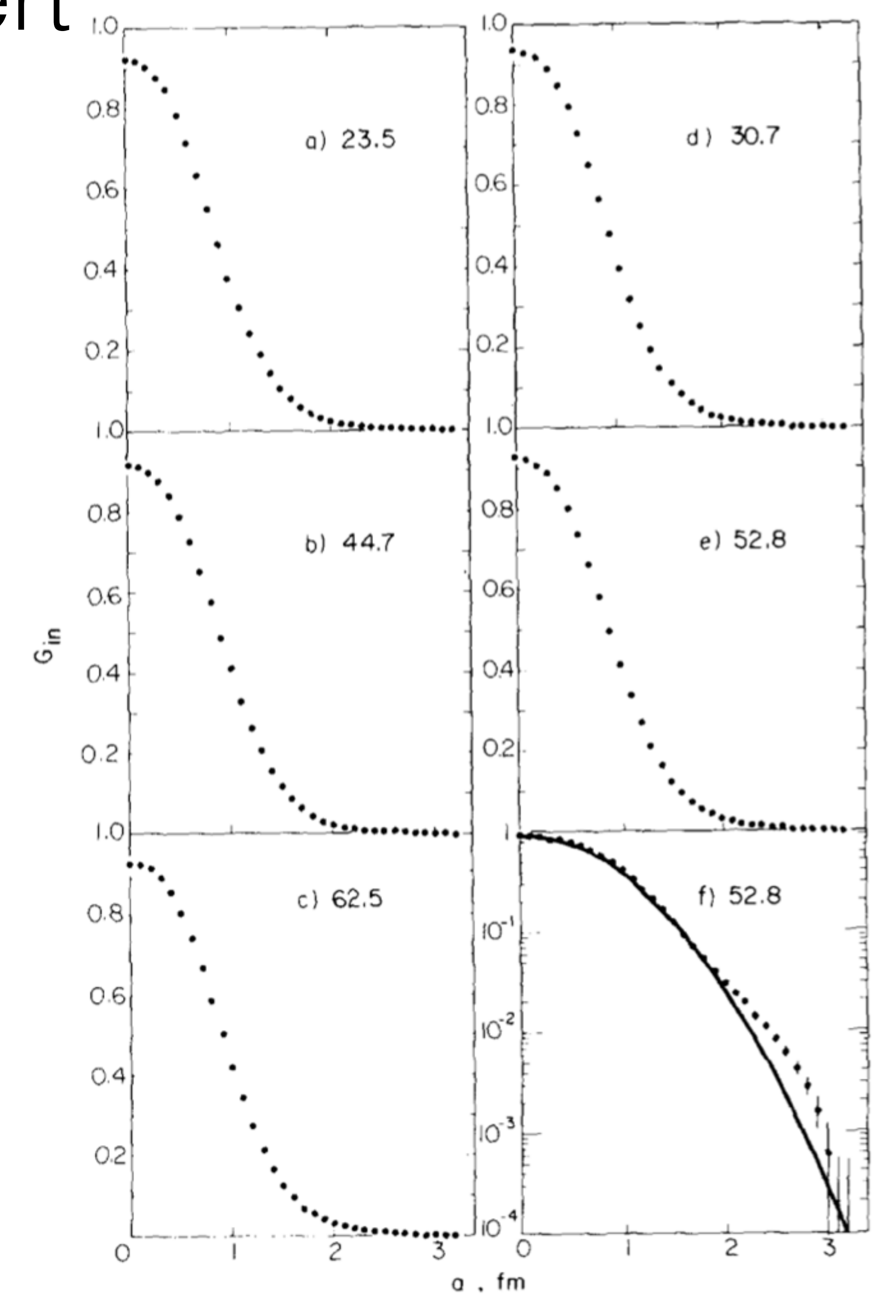


Fig. 5. The inelastic overlap functions as a function of the impact parameter at the five ISR energies. On the linear scale (a-e), the errors on G_{in} are smaller than the points drawn. The solid line on the logarithm scale (f) is a gaussian adjusted to fit at $a = 0$ and $a = 1.6$ fm. A gaussian adjusted between 0.6 and 1.6 fm would be higher at $a = 0$.

what is consequence for this picture of higher "survival Probability" at 7TeV?

we follow a similar analysis

Geometry in impact parameter,b, space:

$$i\Gamma(s,b) = \frac{1}{2\sqrt{\pi}} \int_0^\infty d|t| f(s,t) J_0(b\sqrt{|t|}).$$

Unitarity condition in b-space:

$$G(s,b) = 2\mathrm{Re}\Gamma(s,b) - |\Gamma(s,b)|^2.$$

The most prominent feature of elastic scattering is the rapid decrease of the differential cross section with increasing transferred momentum, $|t|$, in the diffraction peak. As a first approximation, at present energies, it can be described by the exponential shape with the slope $B(s)$:

$$\frac{d\sigma}{dt} = \frac{\sigma_{tot}^2}{16\pi} \exp(-B(s)|t|). \tag{6}$$

The diffraction cone contributes predominantly to the Fourier - Bessel transform of the amplitude. Using the above formulae, one can write the dimensionless Γ as

$$i\Gamma(s,b) = \frac{\sigma_t}{8\pi} \int_0^\infty d|t| \exp(-B|t|/2)(i+\rho) J_0(b\sqrt{|t|}). \tag{7}$$

Here, the diffraction cone approximation (6) is inserted. Herefrom, one calculates

$$\mathrm{Re}\Gamma(s,b) = \zeta \exp(-\frac{b^2}{2B}), \tag{8}$$

where we introduce the dimensionless ratio of the cone slope (or the elastic cross section) to the total cross section

$$\zeta = \frac{\sigma_{tot}}{4\pi B} = \frac{4\sigma_{el}}{(1+\rho^2)\sigma_{tot}} \approx \frac{4\sigma_{el}}{\sigma_{tot}}. \tag{9}$$

With these reasonable approximations the inelastic profile simplifies to a function of 2 parameters:

$$G(s,b) = \zeta \exp(-\frac{b^2}{2B})[2 - \zeta \exp(-\frac{b^2}{2B})].$$

and, in particular at b=0:

$$G(s,b=0) = \zeta(2-\zeta).$$

when comparing the value at different energies we find ISR was at a shallow minimum

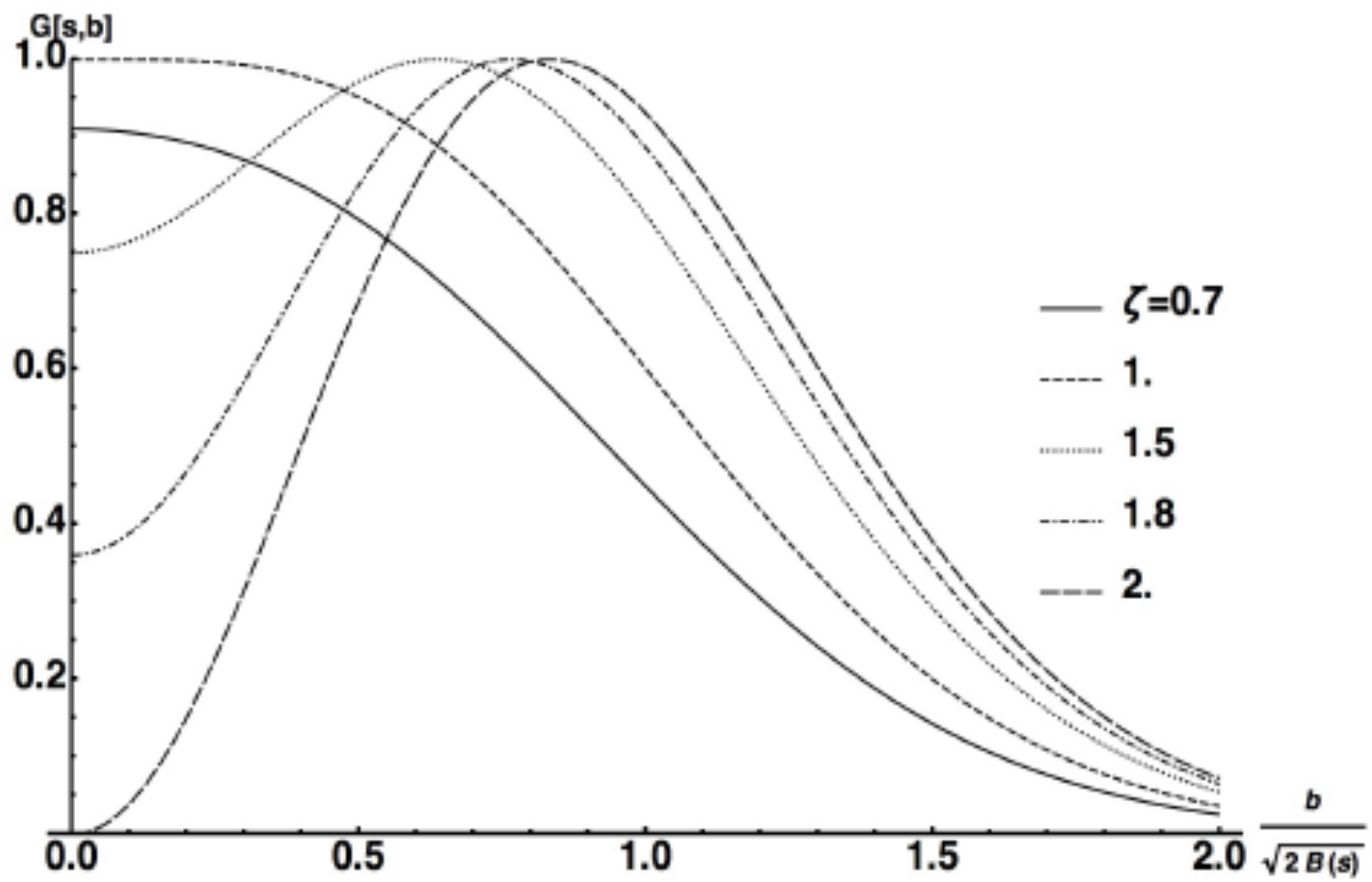
Table. The energy behavior of ζ and $G(s,0)$.

$\sqrt{s}$, GeV	2.70	4.11	4.74	7.62	13.8	62.5	546	1800	7000
ζ	1.56	0.98	0.92	0.75	0.69	0.67	0.83	0.93	1.00-1.02
$G(s,0)$	0.68	1.00	0.993	0.94	0.904	0.89	0.97	0.995	1.00

have we reached an asymptotic value at 7 TeV?

How might this evolve with Energy?

Figure 1: The evolution of the inelastic interaction region in terms of the survival probability. The values $\zeta = 0.7$ and 1.0 correspond to ISR and LHC energies and agree well with the result of detailed fitting to the elastic scattering data [5, 6, 7]. A further increase of ζ leads to the toroid-like shape with a dip at $b = 0$. The values $\zeta = 1.5$ are proposed in [8, 9] and $\zeta = 1.8$ in [10] as corresponding to asymptotical regimes. The value $\zeta = 2$ corresponds to the "black disk" regime ($\sigma_{el} = \sigma_{inel} = 0.5\sigma_{tot}$).



2 basic approximations made simplification to:

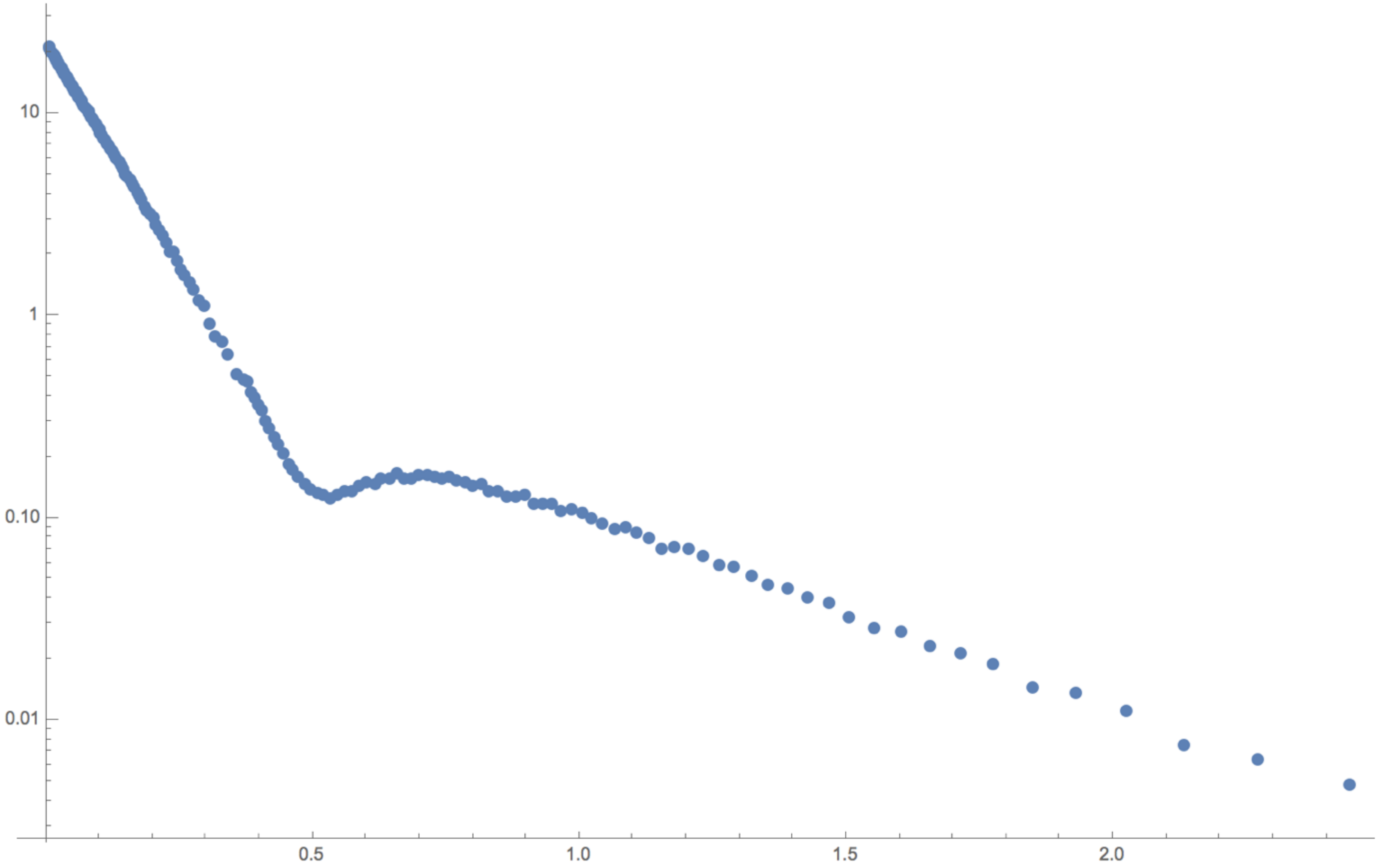
$$G(s, b = 0) = \zeta(2 - \zeta).$$

- which is plotted in previous slide
- small real part->~2% effect @LHC near t=0.
- dominant exponential behavior in t
- we check this latter numerically below

In this notebook we numerically compare the exponential form approximation with the full integral over all t.

```
dat = Import["~bastian/Desktop/totemdata_allt.csv", "CSV"];
Dimensions[dat];
dat1 = Drop[dat, 1];
tbin = Table[dat1[[i, 1]], {i, 164}];
dsdt = Table[dat1[[i, 2]], {i, 164}];
sdsdt = N[Sqrt[dsdt]];

ListLogPlot[Transpose[{tbin, sdsdt}] (*,PlotRange→{{0,0.5},Full}*)]
```

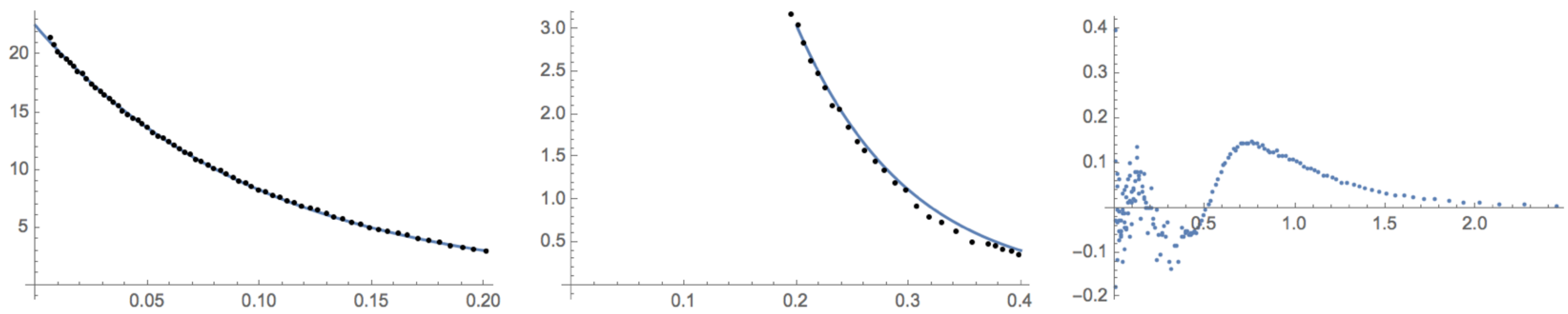



```
dat2 = Take[Transpose[{tbin, sdsdt}], 90];
model = a1 Exp[-k t];
fit = FindFit[dat2, model, {a1, k}, t]
modelf = Function[{t}, Evaluate[model /. fit]]
```

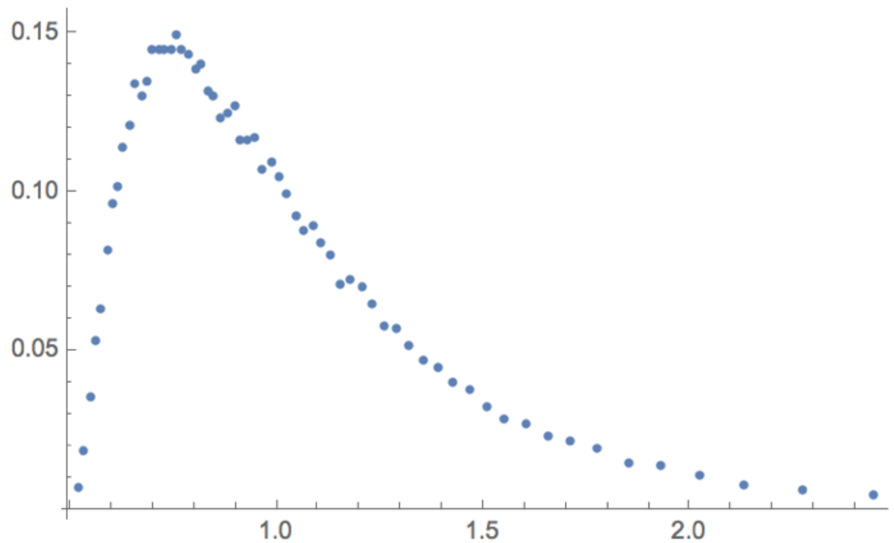
{a1 → 22.597, k → 10.0179}

Function[{t}, 22.597 $e^{-10.0179\,t}$]

```
resid = Table[(sdsdt[[i]] - (22.59 * Exp[-10.0179 * tbin[[i]]])), {i, 164}];
GraphicsRow[{Plot[modelf[t], {t, 0, 0.2}, AxesOrigin → {0, 0}, Epilog → Map[Point, dat2] (*,ImageSize→Large*)],
  Plot[modelf[t], {t, 0.2, 0.4}, AxesOrigin → {0, 0}, Epilog → Map[Point, dat2] (*,ImageSize→Large*)], ListPlot[Transpose[{tbin, resid}]]}]
```



```
tointegrate = Drop[Transpose[{tbin, resid}], 102];
ListPlot[tointegrate]
```



```
fity = FindFormula[tointegrate, x, 5, All]
```

	Score	Error	Complexity
0.0817088	5.962	0.002181	1
0.124551 + 0.562748 Log[Sin[Csc[x]]]	4.695	0.001051	13
Log[Sin[x]]^2	2.62	0.01923	8
Log[x]^2	1.978	0.05095	6
−0.717333 Log[x]	1.582	0.07572	6

2 levels | 5 rows

Determine Bin Widths, Perform Integral as a sum.

```
dt = Table[(tbin[[i + 1]] - tbin[[i]]), {i, 1, 163}];
AppendTo[dt, dt[[163]]];
bruteforce = Sum[sdsdt[[i]] * dt[[i]], {i, 164}]
erro = Sum[resid[[i]] * dt[[i]], {i, 164}]
erro / bruteforce
```

```
2.23927

0.0881214

0.0393527
```

So we have a ~ < 4 % error due to approximation by exponential form. Now do some other numerical comparisons.

```
intexp = Integrate[(22.59 * Exp[-10.0179 * x]), {x, tbin[[1]], tbin[[164]]}]
```

```
2.11285
```

```
intexpft0 = Integrate[(22.59 * Exp[-10.0179 * x]), {x, 0, tbin[[164]]}]
```

```
2.25496
```

```
intexpfull = Integrate[(22.59 * Exp[-10.0179 * x]), {x, 0, Infinity}]
```

```
2.25496
```

```
erro / intexpfull
```

```
0.0390789
```

Now Recall that $G(s, 0) = \xi(2 - \xi)$

so for $\xi \sim 1$ a 4 % error in ξ is $(4\,\%)^2$ error in G. This is really small !

Thank You for Your Attention!